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DRAFT
REGULATORY
STANDARD

Technical and Quality Assurance Requirements for Dosimetry Services

S–106, Revision1

Issued for public comment
January 2005

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DRAFT REGULATORY STANDARD

TECHNICAL AND QUALITY ASSURANCE REQUIREMENTS FOR DOSIMETRY SERVICES, REV. 1

S-106, REV. 1

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About this Document

The purpose of this Regulatory Standard, when incorporated in a dosimetry service licence or other legally enforceable instrument, is to help assure that licensed dosimetry services meet certain technical requirements, and implement certain quality assurance measures, in accordance with the purpose of the *Nuclear Safety and Control Act* ("NSC Act," "Act").

Comments

The Canadian Nuclear Safety Commission (CNSC) invites interested persons to assist in the further development of this draft regulatory document by commenting in writing on the document's content and potential usefulness. Direct your comments to consultation@cnsc-ccsn.gc.ca or the postal address provided below, referencing file 1-8-8-106, by March 24, 2005.

The CNSC will take the comments received on this draft into account when developing it further. Comments that imply a change to the draft regulatory standard should be accompanied by a justification and preferably by suggested text. These comments will be subject to the provisions of the federal *Access to Information Act*.

Document availability

This document can be viewed on the CNSC website at www.nuclearsafety.gc.ca. To order a printed copy in English or French, please contact:

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DRAFT REGULATORY STANDARD

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Technical and Quality Assurance Requirements for Dosimetry Services

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TECHNICAL AND QUALITY ASSURANCE REQUIREMENTS FOR DOSIMETRY SERVICES

1.0 PURPOSE

The purpose of this Regulatory Standard, when incorporated in a dosimetry service licence or other legally enforceable instrument, is to help assure that licensed dosimetry services meet certain technical requirements, and implement certain quality assurance measures, in accordance with the purpose of the *Nuclear Safety and Control Act* ("NSC Act," "Act").

2.0 SCOPE

This Regulatory Standard sets out the technical and quality assurance requirements that a licensed dosimetry service shall meet, when a condition of the applicable licence so requires.

This Regulatory Standard S-106, Rev.1, Technical and Quality Assurance Requirements for Dosimetry Services supersedes the Regulatory Standard S-106, Technical and Quality Assurance Standards for Dosimetry Services in Canada published in March 1998.

3.0 RELEVANT LEGISLATION

The relevant provisions of the NSC Act and the regulations made under the *Act* to this Standard are as follows:

1) Subsection 24(4) of the NSC Act that provides that the Commission may only issue, renew or amend licences if the licensee or the applicant is (a) qualified to carry on the activity that the licence authorize the licensee to carry on, and (b), in carrying out that activity, make adequate provision for the protection of the environment, the health and safety of persons and the maintenance of national security and measures required to implement international obligations to which Canada has agreed;

2) Subsection 24(5) of the NSC Act that provides that a licence issued by the CNSC may contain any term or condition that the CNSC considers necessary for the purposes of the *Act*;

3) Section 18 of the *Radiation Protection Regulations* that provides that an application for a licence to operate a dosimetry service shall contain, in addition to other information, the following:

   (a) "a description of the proposed operation of the dosimetry service;

   (b) the proposed quality assurance program;

   (c) the types of dosimetry services proposed to be provided, including the types of radiation that will be monitored and their respective energy ranges;

(d) the precision, accuracy and reliability of the dosimetry services to be provided; and

(e) the proposed qualification requirements and training program for workers."; and

4) Section 19 of the *Radiation Protection Regulations* that provides that "Every licensee who operates a dosimetry service shall file with the National Dose Registry of the Department of Health, at a frequency specified in the licence and in a form compatible with the Registry, the following information with respect to each nuclear energy worker for whom it has measured and monitored a dose of radiation:

(a) the worker's given names, surname and any previous surname;

(b) the worker's Social Insurance Number;

(c) the worker's sex;

(d) the worker's job category;

(e) the date, province and country of birth of the worker;

(f) the amount of exposure of the worker to radon progeny; and

(g) the effective dose and equivalent dose received by and committed to the worker."

4.0 TECHNICAL REQUIREMENTS

This section provides technical requirements that are specific to external dosimetry, internal dosimetry and the measurement of exposures to radon progeny, radon gas and long-lived radioactive dust. The requirements apply to outside (commercial) service and in-house service.

4.1. Dosimetry Services for External Radiation

An external dosimetry service shall

1) identify, at the licensing stage, the types of radiation and the expected respective energy ranges to which the dosimeters will be exposed during use;

2) measure the quantity of interest within the accuracy specifications and uncertainty limits that apply to that quantity, as described in section 4.1.3;

3) demonstrate its ability to satisfy overall specifications through type testing at the licensing stage and when changes are made, as described in section 4.1.4;

4) demonstrate that it operates in a predictable and consistent way through routine and special performance testing, as described in section 4.1.5; and

5) have its performance and the calibration of its system verified through independent testing, as described in 4.1.6.

Note: These requirements are not applicable to neutron dosimetry services. See section 4.1.7 for requirements that apply to neutron dosimetry services.

The dosimetry service shall notify the Canadian Nuclear Safety Commission (CNSC) immediately, in writing (electronic format acceptable), when it fails one of its periodic tests (i.e., performance or independent test). It shall submit to the CNSC within 30 days a detailed written report outlining the cause of failure and a description of corrective action taken.

The failed test shall be immediately repeated and the dosimetry service shall submit the results to the CNSC. If repetition of the test results in a second consecutive failure, the CNSC may take further licensing action.

4.1.1. Measurement Quantities

4.1.1.1. Torso

The quantity to be measured is the "personal dose equivalent" $H_p(d)$ as defined by the International Commission on Radiation Units and Measurements (ICRU) Report 47 [1]. The values of d are 0.07 mm for shallow (or "skin") dose and 10 mm for deep (or "whole body") dose. The conventionally true value of that quantity is used as the reference value for estimating errors in measurements. In the following sections, $H_{p,c}(d)$ designates the conventionally true value of the quantity $H_p(d)$. For more information, see section A.2 of APPENDIX A.

4.1.1.2. Extremities

The quantity to be measured for a specific extremity is the dose equivalent at a depth of 0.07 mm. For the purpose of this document, this is designated as H_e. The depth is that recommended by the International Commission on Radiological Protection (ICRP) Publication 60 [2]. In the following sections, pursuant to the discussion in section A.2 of APPENDIX A, $H_{e,c}$ designates the conventionally true value of the quantity H_e.

4.1.2. Minimum Measurable Dose Equivalent

A dosimetry service must determine the lowest values of $H_{p,c}(d)$ and $H_{e,c}$ it can measure at the 95% confidence level. These values shall be determined under good laboratory conditions, using the usual calibration radiation at normal incidence to the dosimeter.

4.1.3. Accuracy Specifications and Uncertainty Limits

The requirements of this section do not apply to neutron dosimetry services.

Table 1 lists the overall specifications for accuracy and precision. Type testing, described in section 4.1.4 and APPENDIX B, determine a dosimetry system's ability to meet these specifications. Section A.3 of APPENDIX A describes the calculation methods for analyzing type test results. Section A.4 of APPENDIX A provides example calculations.

TABLE 1 – Accuracy and Precision Specifications

Quantity	Dose (mSv)	Accuracy/Precision
$H_{p,c}(10)$	4 to 10 000	+50% / -33%
	0.4	+100% / -50%
$H_{p,c}(0.07)$	100 to 10 000	+50% / -33%
	10	+100% / -50%
$H_{c,c}$	100 to 10 000	+200% / -67%
	10	+200% / -67%

4.1.4. Type Testing

The requirements of this section do not apply to neutron dosimetry services.

4.1.4.1. Requirements

The dosimetry service demonstrates the ability of its dosimetry system to satisfy overall specification requirements through type testing at the licence application stage. When changes are made that may affect the result of a dose measurement, the dosimetry service shall repeat the type tests to the extent necessary to demonstrate that the specifications of Table 1 of section 4.1.3 continue to be met. Examples of such changes are dosimeter design, badge case filters, dose algorithm and temperature cycles (for thermoluminescent dosimetry (TLD)).

The dosimetry service shall report the results to the CNSC, including the documentation described in section 4.1.4.2, of type tests that have been repeated following changes made to the system and shall obtain CNSC approval prior to the implementation of these changes.

The dosimetry service shall comply with the specifications described in APPENDIX B.

4.1.4.2. Documentation

The dosimetry service shall keep the following records:

1) type test results in a format that clearly shows all the influence quantities and system characteristics that were considered and their range of possible values, as expected by the dosimetry service, based on the intended use of that particular dosimetry system;
2) sample calculations that show how the mean response and the combined standard uncertainty were calculated; and
3) justification for any assumptions made and techniques used.

4.1.5. Performance Testing

The requirements of this section do not apply to neutron dosimetry services.

4.1.5.1. Requirements

The dosimetry service shall conduct routine performance tests. In addition to the routine performance tests, the dosimetry service shall conduct occasional special performance tests to confirm that the performance of the dosimetry system remains consistent with the results of the type tests.

The dosimetry service shall include provisions for routine performance tests during every dosimeter issue period. For extremity dosimetry, performance tests shall be performed at least once every three months. The frequency and nature of special performance tests must be specified in the licence application.

1) For routine performance tests, the dosimetry service shall
    (a) irradiate test dosimeters to known doses, usually under standard exposure conditions (e.g., at normal incidence with the calibration radiation);
    (b) treat test dosimeters in the same way as routine dosimeters; if processing is required, test dosimeters are not identified to the processing laboratory;
    (c) include in the test irradiations, doses comparable to or less than the smaller values in Table 1 of section 4.1.3; and
    (d) establish, in consultation with the CNSC, control limits on the test results.
2) The dosimetry service may maintain constant irradiation conditions and doses over time to permit more valid trend analysis.
3) For special performance tests, the dosimetry service shall subject the dosimeters to a subset of those influence quantities that the type tests showed to be

significant and to which the response of the dosimetry system may have changed as a result of aging or replacement of components.

4.1.5.2. Documentation

1) The dosimetry service shall keep the following records:
   (a) routine performance test procedures; and
   (b) routine and special performance test results.
2) The dosimetry service shall submit the routine performance test procedures to the CNSC for approval at the licensing application stage.

4.1.6. Independent Testing

The requirements of this section do not apply to neutron dosimetry services.

4.1.6.1. Requirements

External dosimetry services must undergo and pass independent testing of each of its dosimeter designs prior to licensing. Upon receipt of a licence, the dosimetry service shall undergo independent testing at regular intervals with a frequency of at least once every 12 months.

The dosimetry service shall have the independent tests performed by the relevant reference calibration centre for external dosimetry in Canada (see APPENDIX J).

If a dosimetry service's dosimeters are of a type that require processing (e.g., TLDs), and if more than one processing unit (e.g., TLD reader) is used by that service, each such unit shall be tested on an annual basis by using it to process at least one set of test dosimeters irradiated by the reference calibration centre. However, if the dosimetry service has documented evidence that shows that all of its processing units respond in a consistent manner, only one unit shall be tested through the reference calibration centre on an annual basis. In the latter case, in order to establish response consistency of the processing units, the dosimetry service must show that the mean response (i.e., the mean calculated dose) of a set of dosimeters processed by any given unit is within ±5% (at the 95% confidence level) of the average of the mean responses obtained from all of the processing units. In addition, the coefficient of variation of dosimeters processed by each unit must not be greater than 0.075 in the case of whole-body dosimeters and 0.2 in the case of extremity dosimeters.

The dosimetry service shall comply with the specifications described in APPENDIX C and APPENDIX D, as applicable.

4.1.6.2. Accuracy Specifications

The accuracy specifications that a dosimetry service must maintain in each of the independent tests for photon and beta radiation are represented in Table 2 by the mean response, $\bar{r}$, and coefficient of variation of the responses for the complete set of measurements. For dosimeters worn on the torso, the mean response corresponds with the complete set of measurements of the air kermas (or exposures) delivered. For dosimeters worn on the extremities, the mean response corresponds with the complete set of measurements of tissue doses delivered.

Table 2 – Accuracy Specifications for Dosimeters

Dosimeter	Mean Response, $\bar{r}$	Coefficient of Variation
Worn on the torso	$0.9 \leq \bar{r} \leq 1.1$	≤ 0.075
Worn on the extremities	$0.75 \leq \bar{r} \leq 1.25$	≤ 0.2

Note: For these tests, the table defines the response relative to the conventionally true value of the appropriate quantity.

4.1.7. Requirements for Routine Neutron Dosimetry Services

A neutron dosimetry service shall

1) for category I neutron dosimetry services, ensure compatibility between the service's neutron dosimeters and the neutron fields in which they are to be used;
2) for category II neutron dosimetry services, include a description of the neutron sources and the expected neutron spectra to which workers will be exposed to demonstrate compatibility between the service's neutron dosimeters and the neutron fields in which they are to be used;
3) document detailed technical descriptions of the dosimeters and associated equipment;
4) record data and prepare reports providing quantitative information on the performance of the dosimeters and the service. No type testing is required, except for the determination that the neutron spectrum is compatible with the fields in which workers may be exposed. The following information shall be recorded as data and provided in reports:
    (a) a description of the calibration source, the calibration field and a reference to the calibration protocol;
    (b) the dose equivalent energy response of the dosimeters;
    (c) a statement on the limitations of the dosimetry system and a qualitative estimate of its accuracy and precision in measuring $H_{p,}(10)$, under the

conditions that the dosimeters are intended to be used, including the variability among the processing components;

(d) an estimate of the lowest value of $H_{p,x}(10)$ that the dosimetry system is capable of measuring at the 95% confidence level; and

(e) the minimum reportable dose; and

5) have the calibration of its system directly traceable to the reference calibration centre (see APPENDIX J) or another recognized national or international laboratory, in consultation with the CNSC.

If neutron survey meters are used instead of personal neutron dosimeters, the dosimetry service shall meet the requirements listed above regarding such instruments. In addition, it shall establish a routine calibration program with the relevant reference calibration centre (see APPENDIX J) or other recognized national or international laboratory, in consultation with the CNSC.

4.1.7.1. Independent Testing

The dosimetry service shall undergo independent testing with the relevant reference calibration centre (see APPENDIX J) prior to licensing and, upon receipt of a licence, at regular intervals with a frequency of at least once every 12 months. This is a consistency test that enables dosimetry services to demonstrate consistency of performance on a periodic basis. The conditions upon which the consistency will be judged are established at the time of licensing. Table 3 shows the pass criteria for the complete set of measurements.

Table 3 – Accuracy specifications for neutron dosimeters

Dosimeter	Mean Response, $\bar{r}$	Coefficient of Variation of the Responses
All types	$0.6 \leq \bar{r} \leq 1.4$	≤ 0.25

The dosimetry service shall comply with the specifications described in APPENDIX E.

4.1.7.2. Performance Testing

The dosimetry service shall establish a program for routine performance tests on the dosimetry systems to be performed on a regular basis, as determined in consultation with the CNSC, and shall submit relevant documentation, including the frequency of the testing, to the CNSC at the licence application stage.

4.1.7.3. Documentation

The neutron doses shall be recorded and reported separately from other types of doses.

4.2. Dosimetry Services for Internal Radiation

An internal dosimetry service shall

1) measure the activities and activity concentrations for selected radionuclides, as described in section 4.2.1;

2) measure the quantity of interest within the accuracy and precision specifications, as described in sections 4.2.2 and 4.2.5;

3) demonstrate that it operates in a predictable and consistent way through performance testing, as described in sections 4.2.3 and 4.2.6;

4) demonstrate that it operates in a reliable way by participating in independent testing, as described in sections 4.2.4 and 4.2.7; and

5) ascertain doses as described in section 4.2.8.

The dosimetry service shall notify the Canadian Nuclear Safety Commission (CNSC) immediately, in writing (electronic format acceptable), when it fails one of its periodic tests (i.e., performance or independent test). It shall submit to the CNSC within 30 days a detailed written report outlining the cause of failure and a description of corrective action taken.

The failed test shall be repeated immediately and the dosimetry service shall submit the results to the CNSC. If repetition of the test results in a second consecutive failure, the CNSC may take further licensing action.

4.2.1. Measurement Quantities

Internal dosimetry services must be capable of measuring the activities and activity concentrations equal to the Minimum Testing Levels (MTLs) shown in Table 4 for the radionuclides for which they are licensed. Values greater than those in Table 4 may be used as MTLs if the internal dosimetry service can demonstrate that the dose consequence per measurement is trivial, i.e., less than 0.01 mSv.

To simulate working conditions, radionuclides other than those listed in Table 4 may be introduced during the required independent testing described in sections 4.2.4 and 4.2.7. These radionuclides are not considered part of the test but are added as interferences to challenge the service's analytical system. Consequently, the dosimetry service may pass the test without identifying or measuring them. However, failure to correct for such interferences would jeopardize performance of the test and may result in a failed test.

TABLE 4 - Minimum Testing Levels (MTL)

Radionuclide	*In Vitro* - Urine Bioassay (Bq/L)	*In Vivo* Bioassay (Bq)
Hydrogen-3 (HTO)	2000	N/A
Carbon-14	2000	3×10^5 (lung)
Iron-59	N/A	2500
Cobalt-57*	25	2500
Cobalt-60	25	2500
Strontium-90	2	N/A
Zirconium / Niobium-95	N/A	2000
Antimony-124	N/A	2000
Iodine-125	20	1000
Iodine-131	20	1000
Cesium-137	20	2000
Cerium-144	250	25000
Radium-226	0.05	5000
Thorium-230	0.02	N/A
Natural thorium**	0.02	150 (lung)
Natural uranium***	25 µg/L	20 mg (lung)
Uranium-235	0.02	30 (lung)
Plutonium-238/239/240	0.01	9000 (lung)
Americium-241	0.05	100 (lung)

Note: * ^{57}Co is used as a surrogate for ^{144}Ce
** Includes both ^{232}Th and ^{228}Th (Dalheimer and Henrichs [3])
*** Includes ^{238}U, ^{234}U and ^{235}U

4.2.2. *In Vitro* Accuracy and Precision Specifications

Table 5 lists the *in vitro* accuracy and precision specifications. To assess compliance with accuracy specifications, bias and precision must be considered separately. The mean relative bias, B must be calculated from replicate measurements, A_i, of each concentration or level of activity, A. Since bias is often greater at lower concentrations near the limits of detection than at higher concentrations, dosimetry service laboratories shall be tested at several concentrations no lower than the MTL.

Table 5 – Accuracy and Precision Specifications

Mean Relative Bias, B	Relative Precision, S_B (Absolute value)
$-0.25 \leq B \leq 0.50$	≤ 0.40

4.2.3. Performance Testing for *In Vitro* Measurements

4.2.3.1. Requirements

The dosimetry service shall conduct routine performance tests. The dosimetry service must include provisions for routine performance tests for *in vitro* bioassay, which are to be performed at least once every three months.

For routine performance tests, the dosimetry service shall

1) prepare the test samples to concentrations of analyte known only to the person preparing the test samples (preparation of test samples must be carried out by an individual other than one who analyzes *in vitro* bioassay sample);
2) determine the concentration of analyte in the test samples;
3) treat the test samples in the same way as, and so that they are indistinguishable from, routine *in vitro* bioassay samples;
4) include in the test samples, concentrations comparable to, or greater than, the values in Table 4 of section 4.2.1;
5) include in the performance tests, the same categories of radionuclides that are included in the independent tests in which the dosimetry service participates; and
6) establish, in consultation with CNSC, control limits on the test results.

4.2.3.2. Documentation

1) The dosimetry service shall keep the following records:
   (a) performance test procedures; and
   (b) performance test results.
2) The dosimetry service shall submit the performance test procedures to the CNSC for approval at the licence application stage.

4.2.4. Independent Testing for *In Vitro* Measurements

4.2.4.1. Requirements

Internal dosimetry services must undergo and pass independent testing prior to licensing. Upon receipt of a licence, the dosimetry service shall undergo independent

testing at regular intervals with a frequency of at least once every 12 months, or other intervals, as determined in consultation with the CNSC.

If a dosimetry service uses more than one measurement instrument (e.g., several liquid scintillation counters for tritium analysis), the instruments that were not used for the independent test shall be verified at regular intervals with a frequency of at least once every 12 months against the measurement instrument that was used for the test. The dosimetry service laboratory shall show that all other measurement instruments also meet the accuracy and precision requirements. The dosimetry service shall take factors, such as chemical recovery, quenching, concentration range, sample preparation methods, etc., into account where applicable.

The dosimetry service shall have the independent tests performed by the relevant reference calibration centre (see APPENDIX J) unless otherwise stated in the dosimetry service licence. If the relevant reference calibration centre does not offer the test, the dosimetry service shall seek CNSC approval to use a different organization to perform the independent tests.

Dosimetry services shall have their analytical performance tested at levels of activity encountered in routine personnel monitoring as well as at expected levels following accidental exposures. Test samples will be spiked with a known quantity of a traceable activity greater than or equal to the MTL. Measurement reproducibility will be tested by providing several identical samples of each level of activity.

The dosimetry service shall comply with the specifications described in APPENDIX F.

4.2.5. *In Vivo* Accuracy and Precision Specifications

Table 6 lists the *in vivo* accuracy and precision specifications.

Table 6 – Accuracy and Precision Specifications

Mean Relative Bias, B	Precision of the Bias, P_a (Absolute Value)
$-0.25 \leq B \leq 0.50$	≤ 0.40

4.2.6. Performance Testing for *In Vivo* Measurements

4.2.6.1. Requirements

The dosimetry service shall conduct routine performance tests. The dosimetry service must include provisions for routine performance tests for *in vivo* bioassay, which are to be performed at least once every three months.

For routine performance tests, the dosimetry service shall

1) determine the activity of a source that contains a quantity of analyte in a phantom that is unknown to the *in vivo* bioassay laboratory (the quantity of analyte in the source must be selected by an individual other than one who performs the *in vivo* bioassay measurement);
2) select the source such that quantity of analyte is equal to, or greater than, the values in Table 4 of section 4.2.1;
3) include in the performance tests, the same categories of radionuclides that are included in the independent tests in which the dosimetry service participates; and
4) set, in consultation with CNSC, control limits on the test results.

4.2.6.2. Documentation

1) The dosimetry service shall keep the following records:
   (a) performance test procedures; and
   (b) performance test results.
2) The dosimetry service shall submit the performance test procedures to the CNSC for approval at the licence application stage.

4.2.7. Independent Testing for *In Vivo* Measurements

4.2.7.1. Requirements

Internal dosimetry services must undergo and pass independent testing prior to licensing. Upon receipt of a licence, the dosimetry service shall undergo independent testing at regular intervals with a frequency of at least once every 12 months, or other intervals as determined in consultation with the CNSC.

Independent tests must be carried out at least once every 12 months so that continuing competence can be demonstrated even if no changes are made to the measurement system. Such factors as variation of source distribution within the phantom, variations in ambient background and positioning error shall be taken into account where applicable.

The dosimetry service shall have the independent tests performed by the relevant reference calibration centre (see APPENDIX J) unless otherwise stated in the dosimetry service licence. If the relevant reference calibration centre does not offer the test, the dosimetry service shall seek CNSC approval to use a different organization to perform the independent tests.

If alterations that may affect calibration are made to the detectors, counting geometry or the electronics of the measurement system, a further independent test is required. Phantoms used for calibration at photon energies below 100 keV must be constructed

of tissue-equivalent material and must be anthropomorphic. For photon energies above 100 keV, acceptable phantoms can be made from other materials.

The dosimetry service shall comply with the specifications described in APPENDIX F.

4.2.8. Interpretation of Bioassay Data

4.2.8.1. Requirements

Ascertaining the Committed Effective Dose

Internal dosimetry services must ascertain and record the committed effective dose to workers from the types of measurements referred to in the licence, taking into consideration appropriate human physiological parameters, and other relevant information on the conditions of exposure.

When ascertaining the committed effective dose to workers, dosimetry services shall consider site-specific parameters, unless other values, e.g., default values or values previously approved by the CNSC, are demonstrated to be appropriate. All key parameters must be documented.

Performance Tests

Internal dosimetry services must participate in a performance test prior to licensing. Upon receipt of a licence, an internal dosimetry service shall participate in a performance test at regular intervals with a frequency of at least once every 12 months, or at other intervals as determined in consultation with the CNSC. Performance tests must be carried out so that continuing competence can be demonstrated even if no changes are made to the procedures, and shall include ascertaining the committed effective doses from hypothetical exposure scenarios that are relevant to the activities carried on by CNSC licensees that use the dosimetry service.

The internal dosimetry service shall have the performance test administered by the relevant calibration centre (see APPENDIX J) unless otherwise stated in the dosimetry service licence.

4.2.8.2. Documentation

The dosimetry service shall submit the procedures for ascertaining the committed effective dose to workers, to the CNSC for approval at the licence application stage.

4.3. Dosimetry Services for Radon Progeny, Radon Gas, and Long-Lived Radioactive Dust

Monitoring for radon progeny, radon gas, and long-lived radioactive dust (LLRD) helps to estimate individual doses or exposures to those radiological risks for workers in uranium processing facilities. Estimates are made through grab sampling measurements combined with occupancy time records or through personal monitoring.

A dosimetry service for radon progeny and radon shall

1. determine the lowest exposure or concentration in air that it can measure at the 95% confidence level with the overall accuracies specified, as described in section 4.3.2;
2. measure the quantity of interest within the accuracy specifications and uncertainty limits that apply to that quantity, as described in sections 4.3.3 and 4.3.6;
3. demonstrate its ability to satisfy overall specifications through type testing, as described in sections 4.3.4 and 4.3.7; and
4. demonstrate that it operates in a reliable way through independent testing, as described in sections 4.3.5 and 4.3.8.

The dosimetry service shall notify the Canadian Nuclear Safety Commission (CNSC) immediately, in writing (electronic format acceptable), when it fails one of its periodic tests (i.e., independent test). It shall submit to the CNSC within 30 days a detailed written report outlining the cause of failure and a description of corrective action taken.

The failed test must then be repeated immediately and the dosimetry service shall submit the results to the CNSC. If repetition of the test results in a second consecutive failure, the CNSC may take further licensing action.

Type testing methods, criteria and facilities, and independent testing facilities are not currently available for LLRD measurements. Therefore this standard specifies no requirements for type testing and independent testing for LLRD measurements. However, a dosimetry service for LLRD shall

1. determine the lowest exposure or concentration in air that it can measure at the 95% confidence level with the overall accuracies specified, as described in section 4.3.2; and
2. measure the quantity of interest within the accuracy and relative precision specifications that apply to that quantity, as described in section 4.3.9.

4.3.1. Measurement Quantities

The quantities to be measured are

1) the concentration in air of potential alpha energy from short-lived radon progeny,
2) the exposure to airborne short-lived radon progeny,

3) the concentration in air of radon gas, and

4) the concentration in air of long-lived radioactive dust.

There are historical and SI (Système international d'unités), or SI-compatible, units of measurement for the concentration of short-lived radon progeny in air and exposure to radon progeny. In this section historical units are given first, followed by SI or SI-compatible units in parentheses.

The Working Level (WL) is the historical unit for the measurement of radon progeny concentration in air. The corresponding SI unit is the joule per cubic metre ($J\ m^{-3}$):

$1\ WL = 20.8\ \mu J\ m^{-3}$ $1\ \mu J\ m^{-3} = 4.8 \times 10^{-2}\ WL$

The Working Level Month (WLM) is the historical unit used to express exposures to radon progeny. The SI-compatible unit is the joule-hour per cubic metre ($J\ h\ m^{-3}$):

$1\ WLM = 3.54\ mJ\ h\ m^{-3}$ $1\ mJ\ h\ m^{-3} = 0.283\ WLM$

The concentrations of radon and LLRD in air are measured in activity per unit volume of that atmosphere (i.e., $Bq\ m^{-3}$). The intake (Bq) from this concentration is calculated by multiplying the concentration by a defined breathing rate (i.e., $1.2\ m^3\ h^{-1}$) and the occupancy time (h). Alternatively, exposure can be determined in $Bq\ h\ m^{-3}$ and the intake would be this value multiplied by the breathing rate.

4.3.2. Minimum Measurable Exposure or Concentration

A dosimetry service must determine and record the lowest exposure or concentration in air that it can measure at the 95% confidence level with the overall accuracies of +50%/-33%. The minimum measurable exposure shall be expressed in the same units as the measured quantity.

Section H.1 of APPENDIX H provides examples of the statistical method used to determine the minimum measurable activity concentration for LLRD.

4.3.3. Accuracy Specifications and Uncertainty Limits for Radon Progeny Measurements

Two categories of instruments monitor individual exposures to radon progeny: personal monitors, which give a direct estimation of individual exposures; and grab sampling instruments, which provide a measure of radon progeny concentration at a given place and time, and whose readings are used in combination with occupancy time records to calculate individual exposures. Both categories of instruments must meet the corresponding requirements of this section.

95% of the values obtained in a series of measurements taken in an environment with stable and fixed concentration shall fall within the confidence interval limits, as indicated in Tables 7 and 8.

Table 7 provides the accuracy specifications of the measurement of the exposure value given from the reading of a personal monitor for a dosimetry period.

TABLE 7 - Performance Specifications for Measurement of Exposure to Radon Progeny for One Dosimetry Period

Range of Measurement	Overall Accuracy (95% Confidence)
$\geq$ 0.05 WLM (177 μJ h m^{-3}) to < 0.10 WLM (354 μJ h m^{-3})	+100% / -50%
$\geq$ 0.10 WLM (354 μJ h m^{-3})	+50% / -33%

Table 8 provides the accuracy specifications for the measurement of the concentration in the air of potential alpha energy contained in radon progeny, using grab sampling measurements.

TABLE 8 - Performance Specifications for Measurement of Concentration of Potential Alpha Energy in Air

Range of Measurement	Overall Accuracy (95% Confidence)
$\geq$ 0.05 WL (1.03 μJ m^{-3}) to < 0.10 WL (2.08 μJ m^{-3})	+100% / -50%
$\geq$ 0.10 WL (2.08 μJ m^{-3})	+50% / -33%

4.3.4. Type Testing for Radon Progeny Measuring Instruments

4.3.4.1. Requirements

The dosimetry service demonstrates the ability of its dosimetry system to satisfy overall specification requirements through type testing at the licence application stage. When changes are made (e.g., to the instrumentation or methods used) that may affect the performance of personal monitors and grab sampling instruments, the dosimetry service shall repeat the type tests with respect to measurement accuracy and precision to the extent necessary to demonstrate that the specifications of Tables 7 and 8 continue to be met.

Type testing procedure for instruments used to determine exposures to radon progeny (e.g., personal monitors) shall identify all possible sources of error and quantify their contribution to the overall error and uncertainty in individual exposures. In addition to establishing a personal monitor's overall accuracy, the type testing procedure shall indicate the limitations of the device, such as conditions that may result in the onset of filter saturation problems, the time during which the device can be reliably used without the need to recharge the battery, etc.

Type testing for grab sampling instruments shall identify and quantify all possible sources that contribute to the overall error and uncertainty in measured instantaneous radon progeny concentrations. Errors and uncertainties in actual personal exposures that are derived from grab sampling measurements are excluded.

In type testing, the following influence quantities shall be considered, and those that are likely to significantly affect accuracy or uncertainty shall be evaluated. Other influence quantities that may contribute to the overall uncertainty shall also be considered (i.e., all influence quantities contributing to the uncertainty of the measurement shall be taken into account).

1) For personal monitors, the following quantities shall be taken into account:
    (a) Sampling Parameters
        i) duration of operation at design performance at full charge of the battery
        ii) sampling flow rate
        iii) flow rate variability
        iv) influence of particle size distribution, and particularly unattached fraction of radon progeny on sampling efficiency
    (b) Detection and Counting Parameters
        i) filter-detector geometry
        ii) energy-dependent detection efficiency
        iii) sensitivity to radiation emitted from sources other than radon progeny
        iv) sensitivity to deviations from detector processing specifications
        v) sensitivity to time variability of radon progeny concentrations.
2) For grab sampling instruments, the following quantities shall be taken into account:
        i) sampling flow rate
        ii) flow rate variability
        iii) sensitivity to particle size distribution, and particularly unattached fraction of radon progeny in the test atmosphere
        iv) calibration and stability of field alpha counters
        v) the method used to calculate radon progeny concentrations.

The dosimetry service shall report the results to the CNSC, including the documentation described in section 4.3.4.2, of type tests that have been repeated following changes made to the system and shall obtain CNSC approval prior to the implementation of these changes.

4.3.4.2. Documentation

The dosimetry service shall keep the following records:

1) type test results in a format that clearly shows all the influence quantities and system characteristics that were considered, and their range of possible values, as expected by the dosimetry service, based on the intended use of that particular dosimetry system;
2) sample calculations that show how the mean response and the combined standard uncertainty were calculated; and
3) justification for any assumptions made and techniques used.

4.3.5. Independent Testing for the Monitoring of Radon Progeny

4.3.5.1. Requirements

The dosimetry service shall undergo independent testing to demonstrate that it meets the accuracy and relative precision specifications, as described in section 4.3.3.

The dosimetry service shall have the independent tests performed through the relevant reference calibration centre for the monitoring of radon progeny in Canada (see APPENDIX J).

The dosimetry service shall send a representative sample of its personal monitors to the reference calibration centre at regular intervals with a frequency of at least once every 12 months, or at other intervals, as determined in consultation with the CNSC, and also following any changes in design that could affect the performance of monitors.

The dosimetry services that use grab sampling shall comply with the specifications described in APPENDIX G.

4.3.6. Accuracy and Relative Precision Specifications for Radon Gas Measurements

Under the expected conditions of use, the monitoring systems used to evaluate concentrations of, or exposures to, radon must be able to produce values with the following accuracy and relative precision:

within + 50% and - 33% from the true values, 95% of the time.

This means that 95% of the values obtained in a series of measurements taken in an environment with stable and fixed concentration shall fall within the confidence interval limits.

4.3.7. Type Testing for Personal Radon Gas Monitors

4.3.7.1. Requirements

The dosimetry service demonstrates the ability of its dosimetry system to satisfy overall specification requirements through type testing at the licence application stage. If the monitor design is changed (i.e., different detector or filters, different casing, etc.), the dosimetry service shall repeat the type tests to the extent necessary to demonstrate the influence on overall accuracy and uncertainty.

Type testing for instruments used to determine exposures to radon shall identify all possible sources of error and shall quantify their contribution to the overall error and uncertainty in individual exposures.

The following influence quantities shall be considered and those that are likely to significantly affect accuracy or uncertainty shall be evaluated. Other influence quantities that may contribute to the overall uncertainty, in addition to those listed here, shall also be considered.

The following quantities shall be taken into account:

(a) detection geometry

(b) humidity

(c) static electricity

(d) calibration

(e) airborne dust

(f) sensitivity to radiation other than from radon, or to other agents

(g) saturation

(h) durability for the work environment.

4.3.7.2. Documentation

The dosimetry service shall keep the following records:

1) type test results in a format that clearly shows all the influence quantities and system characteristics that were considered, and their range of possible values, as expected by the dosimetry service, based on the intended use of that particular dosimetry system;

2) sample calculations that show how the mean response and the combined standard uncertainty were calculated; and

3) justification for any assumptions made and techniques used.

4.3.8. Independent Testing for Radon Gas Measurements

The dosimetry service shall undergo independent testing to demonstrate that it meets the accuracy and relative precision specifications described in section 4.3.6.

The dosimetry service shall have the independent tests performed through the relevant reference calibration centre for the monitoring of radon gas in Canada (see APPENDIX J).

The dosimetry service shall send a representative sample of its personal monitors to the reference calibration centre at regular intervals with a frequency of at least once every 12 months, or at other intervals, as determined in consultation with the CNSC, and also following any changes in design that could affect the performance of monitors.

The dosimetry service shall comply with the specifications described in APPENDIX G.

4.3.9. Accuracy and Relative Precision Specifications for LLRD Measurements

The CNSC will assess the accuracy of LLRD measurements from the quality and reliability of the sampling and counting systems used. Sampling procedures considered to be reliable by industrial hygienists will also be considered to be adequate for sampling airborne LLRD, provided that references[1] that the CNSC considers appropriate support their reliability.

The dosimetry service shall demonstrate that it follows standard good practices expected in routine industrial hygiene monitoring in the measurement of LLRD concentration in air. In particular, the flow rate of sampling pumps must not deviate by more than 5% from the value used to calculate concentration.

Since all inhaled radionuclides, whatever the size of the carrier particle, ultimately contribute to the committed dose, air sampler dust collection efficiency must be size-insensitive, to the greatest extent possible. This excludes the use of cyclones to collect and measure airborne radioactive dust.

The dosimetry service shall determine the overall uncertainty in LLRD measurements from the combination of all the uncertainties in all the parameters used to derive the LLRD concentration from the alpha activity measured on the monitor's filter.

[1] Including but not limited to: U.S. Department of Labor Occupational Safety & Health Administration (OSHA) Technical Manual Section II: Chapter 1 Personal Sampling for Air Contaminants; National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods (NMAM®), 4th ed., Publication 94-113; or International Organization for Standardization ISO 2889:1975 - General principles for sampling airborne radioactive materials.

Section H.2 of APPENDIX H provides examples of the statistical method used to estimate uncertainties in counting for LLRD.

5.0 QUALITY ASSURANCE REQUIREMENTS

5.1. General

Accuracy and repeatability of dose measurements define quality in a dosimetry service. The objective of a quality assurance program in a dosimetry service is to implement a management system that ensures dosimetry results are accurate, repeatable, verifiable, and properly recorded. The following requirements represent a minimum basis for developing an effective quality assurance program in a dosimetry service.

5.2. Quality Assurance Program Requirements

5.2.1. Management Policy

1) Top management shall document its quality policy. The quality policy will be appropriate for a dosimetry service (see section 5.1) and will include a commitment to operate according to its quality assurance program, to regularly review its adequacy, and continually improve.

2) The quality policy and objectives will be communicated to staff.

5.2.2. Quality Assurance Program Description

The description of the quality assurance program shall consist of interrelated documents that collectively provide clear, comprehensive, and accurate descriptions of the following information:

1) Statements of quality policy and quality objectives.

2) Documented procedures and instructions.

3) Documents needed by the dosimetry service to ensure effective planning, operation, and control of its processes.

4) Records required to demonstrate compliance with the quality assurance program.

5) Note: The documentation can be in any form or medium.

5.2.3. Review by Management

1) Managers shall perform self-assessments of their responsible areas on an on-going basis. Self-assessments shall determine whether the dosimetry service meets quality standards and objectives, and effectiveness of its processes and procedures. Performance metrics shall be developed and used in self-assessments.

2) At least annually, senior management shall conduct a formal review to ensure that processes are optimized, under control, and producing accurate results that conform to specifications. The review shall include assessing opportunities for

improvement and the need for changes in the quality assurance program, including the quality policy and objectives. The annual review shall include at a minimum the following sources of information:

(a) comparisons of quality objectives and standards against actual achievements;

(b) analyses of inspection and test results;

(c) analyses of non-conformances (frequency, significance, consequence, cause, accountability) of corresponding preventive measures and of deficiency trends;

(d) analyses of results from internal audits;

(e) complaints and implementation problems or errors;

(f) results of management self assessments; and

(g) analysis of the effectiveness of corrective actions.

3) Records of the reviews shall be maintained.

5.2.4. Organization and Authority

1) Management shall define the responsibilities and authorities of managers and staff. The lines of internal and external communications shall be defined.

2) Management shall appoint an individual who will be responsible for independently assessing the effectiveness of the quality assurance program, and who reports to a level of management such that sufficient freedom from the pressures of cost and schedule considerations is preserved.

5.2.5. Personnel Qualifications

1) All personnel performing dosimetry service activities, including those described in section 5.2, shall have the training, qualifications and competence necessary to perform their assigned tasks effectively.

2) Standards of training, qualification and competence shall be set by the dosimetry service.

5.2.6. Procurement

1) Purchasing equipment and material necessary for accurate dose or exposure measurement shall be controlled by procedures established by the dosimetry service.

2) Purchasing procedures shall ensure that purchased materials conform to specified purchase requirements. Specified purchase requirements shall include preparation of a clear description of the item using a requirement or technical data sheet that includes measuring accuracy and repeatability, traceability of calibration to national standards, inspection and testing specifications,

acceptance criteria, quality assurance program specifications that the supplier must meet, and recording specifications.

3) Suppliers shall be evaluated and selected based on their ability to meet specifications.

4) Purchased materials and equipment shall be verified as meeting specified purchase requirements.

5.2.7. Work Control

1) All work or activities that can influence the assignment of the correct dose to the right individual and the maintenance of an effective dose record system shall be controlled by established procedures that provide details of the following items, for example:

   (a) work methods and sequence,

   (b) equipment to be used and special working environments,

   (c) acceptance criteria,

   (d) inspection points, and

   (e) logging specifications.

2) Work control procedures shall control the preservation of identification through marking and number control of dosimeters, samples, standards, measurements, dose records, and other data on which dose is based, and maintaining their traceability to the individuals concerned.

3) Work control procedures shall prescribe specifications and special precautions to control the handling, storage and shipping of dosimeters and samples to protect against loss of sensitivity, loss of information, loss of accuracy, and against damage to, or complete loss of the dosimeters or samples. Distribution, use and handling of control dosimeters and handling of samples shall also be described.

4) Conclusions regarding assigned dose shall be adequately documented to enable traceability to the input data (e.g., identification information, measurements and models used) and to show conformance to standards.

5) The method of transferring dose data shall meet the specifications described in APPENDIX I.

5.2.8. Change Control

1) Changes to dosimetry processes and dose records shall be controlled.

2) Change control shall provide equivalent reviews and approvals to those applied to the original dosimetry processes, dose records, or both.

3) Proposed changes shall be reviewed and approved by qualified persons before implementation.

4) Records of proposed and implemented changes shall be kept. Procedures shall prescribe standards to ensure that changes to dose records are properly documented.

5) Where changes involve a revision to approved procedures and instructions, the specifications of section 5.2.9 shall be met.

6) Note: Users of dosimetry services make requests to the CNSC to change dose records by following the requirements of CNSC S-260 [4].

5.2.9. Document Control

1) Procedures shall be established for the preparation, review, approval, issue, distribution, and revision of documents and procedures. In particular, this includes those documents and procedures that contain technical specifications or prescribe activities for the achievement and verification of technical specifications. Examples are technical standards, dosimetry manuals, specifications and procedures for dose records, operating procedures, software programs, calibration techniques, and analytical methods. It also includes the quality assurance program procedures.

2) Documents shall be legible, available, and readily identifiable.

3) Documents shall be removed from use when obsolete or clearly identified as obsolete if retained for other uses.

5.2.10. Calibration and Maintenance

1) Recording, measuring, testing, analyzing or counting devices, instruments or standards whose performance is critical to accurate dose measurements shall be identified, controlled and maintained.

2) Such devices, instruments, and standards shall be of a type, sensitivity and accuracy that meet the appropriate minimum specifications set out in section 4.0.

3) Periodic calibration and maintenance requirements shall be determined based on the necessary accuracy, purpose, degree of usage, stability characteristics, and other factors affecting measurement control.

4) Maintenance and calibration procedures shall be documented.

5) Calibration status shall be recorded and maintained, and calibrated equipment shall be clearly and indelibly identified (e.g., through the use of labels). When calibration is performed before use or with a high frequency (e.g., daily), logging of calibrations may be sufficient.

6) Inaccurate, uncalibrated, or malfunctioning equipment shall be removed from use.

7) Calibrations shall be traceable to national reference standards. Equipment used as calibration transfer standards shall have calibration traceable to national standards. Where calibrated reference standards are used as transfer standards to

set the reference level by which data is directly measured, methods shall be established to preserve the integrity of the process and the results.

8) When equipment is found to be inaccurate (see section 5.2.12), reviews shall be conducted to determine the validity of data or results and corrective action is taken to prevent a repeat (see section 5.2.13).

5.2.11. Verification

1) Verifications of the intermediate and final stages of work shall be identified, planned, resourced, controlled, documented, and conducted in accordance with defined acceptance and performance criteria.

2) Verification shall be carried out by qualified persons other than those who have participated in the work being verified.

3) The method, timing and results of the verifications shall be recorded, and the person performing the verification shall be identified in the record.

4) Inspections, checks and reviews shall be identified and planned to verify that work is performed (see section 5.2.7(1) to (4)) in an acceptable manner.

5) The dosimetry service operator must participate in independent tests as described in section 4.0. Discrepancies shall be processed according to the specifications provided in sections 5.2.12 and 5.2.13.

5.2.12. Non-Conformance

1) Non-conforming items, services and activities shall be identified, reported, and documented.

2) Non-conformances shall be reviewed and remedial actions identified, executed, verified and recorded. The impact of a non-conformance on previous work shall be assessed for potential effects on dose assignments.

3) Non-conforming items or services shall be controlled to prevent unauthorized use.

4) Backup arrangements in case of equipment or other failure or error shall be described.

5) Note: Non-conformances may occur as a result of, for example, inadequate procedures, equipment failure, equipment inaccuracy, calculation error, wrong identification, wrong input data, the use of inappropriate dosimeter or sample, or improper handling or processing of information.

5.2.13. Corrective Action

1) Significant or recurring non-conformances shall be analyzed to determine their cause, and corrective action taken to prevent repetition.

2) The cause and the subsequent corrective action shall be reported to the appropriate level of management, and follow-up reviews conducted to verify the effectiveness of the corrective action.

3) Note: Significant non-conformances are those that lead to, or could lead to, an undetected overexposure, an incorrect dose being assigned to an individual, or a dose being assigned to the wrong person.

5.2.14. Records

1) The identification, storage, protection, retrieval, and disposition of records shall be controlled. Acceptable formats for records will be defined.

2) Records shall be prepared and retained as evidence of the satisfactory accomplishment of specified activities and the acceptability of results. Sufficient records shall be retained to support final conclusions and to show traceability.

3) Records generated during the determination of the dose results shall be retained for a minimum period ending 5 years after the expiry of the dosimetry service licence.

4) Sufficient records and documentation shall be prepared during the work process to enable reasonable re-creation and checking of results from the referenced input data.

5) A list of records that relate to the licensed operation shall be maintained. Retention periods for these records will be specified.

6) Records shall remain legible, readily identifiable and retrievable as and when needed.

7) Records shall be maintained in a secure manner to protect against the release of personal information, in accordance with relevant applicable legislation.

5.2.15. Independent Audits

1) Management shall have an internal audit program. The internal audit program shall be designed to determine whether the quality assurance program is effectively implemented and resulting in satisfactory performance of the dosimetry service. Internal audits shall be carried out at periodic intervals.

2) Internal audits shall be planned and performed by appropriately trained personnel. Auditors will not have direct responsibility for the activity being assessed.

3) Audit results shall be documented and reviewed by the manager responsible for the activity that has been assessed. This person shall take action to correct any

deficiencies and their causes. Follow-up actions shall include verification of actions taken (see section 5.2.13).

4) Note: See CAN/CSA-ISO 19011:03 [5] for guidance.

6.0 ANNUAL REPORTING REQUIREMENTS

Within 90 days after the end of the calendar year, a licensed dosimetry service must submit a written report to the CNSC summarizing its activities during that calendar year. The report shall contain the following information, where applicable:

1) a summary of the routine and special performance test results performed during the year;

2) a brief description of non-conformances and subsequent corrective actions;

3) a summary of any changes in key technical and quality assurance dosimetry service personnel, including management;

4) a summary of pertinent training given to dosimetry service personnel;

5) the number of dose records for which incomplete information has been provided by the users during the year (see APPENDIX I) as well as the current total, and a summary of efforts towards reducing that number;

6) a list of major dosimetry service equipment permanently brought into or removed from service during the year and an indication that Regulatory Standard S-106, Rev.1 was not compromised;

7) the approximate number of dosimeters in service;

8) the number and type of in vitro bioassay samples analysed;

9) the number and type of in vivo counts carried out;

10) the number and type of non-routine in vivo, in vitro, or both bioassay analyses performed;

11) a summary of the dosimetry system performance in the independent tests; and

12) information on new Quality Assurance initiatives, i.e. results of new tests, different tests or both of the dosimetry process.

GLOSSARY

For the purpose of this document, the following terms and definitions apply. Statistical terms used in this document but excluded from the list below are defined in the Health Physics Society standard N13.30 [5].

Bioassay
Measurement of the amount or concentration of radioactive material in the body, or in biological material excreted from the body and analyzed for purposes of estimating the quantity of radioactive material in the body. The term "bioassay" includes both *in vitro* and *in vivo* measurements.

CNSC
Canadian Nuclear Safety Commission

Coefficient of Variation, C
A measure of reproducibility of the measurements. It is defined as

$$C = \frac{s}{m}$$

where

s = standard deviation of the set of measurements;

m = mean of the set of measurements.

Dosimetry Service
An organization or part of an organization in charge of estimating either radiological doses or exposures to monitored workers, or parameters related to such doses or exposures.

Categories of Dosimetry Service

Category I: An outside or commercial service or laboratory that carries out dosimetry measurements for one or more CNSC licensees.

Category II: An in-house service operated by a licensee that carries out dosimetry measurements for workers and for visitors to the licensed premises.

Types of Dosimetry

External dosimetry: Usually employed for photon (i.e. X and gamma) radiation, but may also be used for beta and neutron radiation.

Internal dosimetry: Involves bioassay in the form of either *in vitro* monitoring (i.e., the analysis of urine, faecal, breath or other samples of biological material), or *in vivo* monitoring (i.e., the direct measurement by external detectors of body or organ burdens of radioactivity), or a combination of the two.

The measurement of radioactive atmospheres: Usually accomplished by means of air monitoring techniques. Typical measurements are for radon progeny and radioactive dusts in uranium mines.

Extremities
Used to refer to the parts of the human body that are furthest from the head and torso, and that share similar sensitivities to ionizing radiation. The extremities are defined as those parts of the anatomy from and including the elbows to the tips of the fingers (i.e., upper extremities) and from and including the knees to the tips of the toes (i.e., lower extremities).

ICRP
International Commission on Radiological Protection

ICRU
International Commission on Radiation Units and Measurements

Independent Testing
Participating in tests conducted by the applicable reference calibration centre. Independent testing helps the dosimetry service demonstrate that the service's results are reliable and meet the CNSC regulatory requirements, including the requirements of this document.

Influence Quantity
A quantity that may affect the accuracy or uncertainty of a measurement.

***In Vitro* Measurement**
Measurement to determine the presence of, or to estimate the amount of, radioactive material in excreta or in other biological materials removed from the body. The term "*in vitro* measurement" is synonymous with indirect bioassay.

***In Vivo* Measurement**
Measurement of radioactive material in the human body using instrumentation that detects radiation emitted from radioactive material in the body. The term "*in vivo* measurement" is synonymous with direct bioassay.

LLRD
Long-lived radioactive dust

Mean Relative Bias, B
The relative accuracy of a set of measurements (i.e., how closely the measurements correspond to the actual radionuclide concentration or activity in analysed samples). It is defined as

$$B = \frac{1}{n}\sum_{i=1}^{n} B_i$$

where

n = number of measurements in the set;

$$\frac{A_i - A}{A}$$

Bi = relative bias of a single measurement =

where

A_i = value of a single measurement;

A = conventionally true value.

Minimum Measurable Concentration (MMC)
Smallest amount (activity or mass) of an analyte in a sample that can be detected. It is implied that there is a *probability b* of failing to detect a quantity of analyte that is present (Type II error) and a *probability a* of erroneously deciding that a positive (non-zero) quantity of analyte is present when it is not (Type I error).

Minimum Testing Level (MTL)
Smallest amount of radioactive material that the dosimetry service must be able to measure as part of the independent testing program. Samples or phantoms provided to dosimetry service applicants or licensees for the independent tests must contain at least the MTL in order to be considered part of the tests required in this Regulatory Standard.

Performance Testing
A testing exercise performed to verify that a dosimetry system is operating in a predictable and consistent way.

PMMA
Polymethylmethacrylate

Precision of the Bias, P_B
A measure of the reproducibility of the results in a series of *in vivo* measurements made on all phantoms. It is defined as

$$P_B = \sqrt{\frac{\sum_{i=1}^{n} (B_i - B)^2}{n-1}}$$

where

Bi = relative bias of a single measurement;

B = mean relative bias;

n = number of measurements made on all phantoms.

Relative Precision, S_B
A measure of the reproducibility of an analysis. It is defined as

$$S_B = \frac{s}{A}$$

where

s = standard deviation of a series of measurements of a variable with a known, true value A

Response, R
The result of a dose measurement under defined conditions divided by the conventionally true dose that would be received under those conditions.

SI
Système international d'unités

TLD
Thermoluminescence dosimeter

Type Testing
An extensive testing exercise which is performed to identify all potential sources of error and uncertainty in the measurement and to quantify those errors and uncertainties that may contribute significantly to the overall error or combined standard uncertainty.

WL
Working levels

WLM
Working level month

REFERENCES

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APPENDIX A
ACCURACY AND UNCERTAINTY IN EXTERNAL DOSE MEASUREMENT

A.1 INTRODUCTION

This appendix provides information and instructions on how to demonstrate that the accuracy and precision requirements of this standard can be met. An example calculation illustrates how various quantities are evaluated.

A.2 CONVENTIONALLY TRUE VALUE

In principle, the objective of personal dosimetry is to measure the quantity "personal dose equivalent," $H_p(d)$, as defined by ICRU Report 47 [1]. The values of d are 0.07 mm for shallow (or "skin") dose and 10 mm for deep (or "whole body") dose. In practice, the "true" value of a quantity cannot be determined, as explained in the International Organization for Standardization ISO *Guide to the expression of uncertainty in measurement*[6]. Instead, the result of a measurement is compared with the "conventionally true value" of that quantity to assess errors in the measured results.

Even if a perfect measurement of $H_p(d)$ were possible, its definition would lead to different expected "true" values for persons of different sizes and shapes who are exposed to the same photon radiation field. It is, therefore, an unsuitable quantity to use for specification of the performance and properties of a dosimeter. A conventionally true value of $H_p(d)$ replaces the true measurement. In the case of photon radiation, for example, the conventionally true value is established by measuring the free-in-air air kerma (or exposure) in a well-defined field with a calibrated instrument, and by applying a conversion coefficient to the result. A computer model calculates the conversion coefficient to simulate irradiation of a standard phantom, which approximates the torso of a human body. The conventionally true value obtained in this way is assumed to have a negligible uncertainty compared with the uncertainty in routine dose measurements; therefore, it is used as the reference value for estimating errors in the latter measurements.

A.3 ACCURACY AND PRECISION

The information contained in this section follows the method developed by C. R. Hirning and P. S. Yuen (Hirning and Yuen [7]). The specifications at the end of this section are based on the recommendations of the ICRP Publication 60 [2], ICRP Publication 75 [8] and on the CNSC requirement that external dosimetry services achieve levels of performance consistent with the use of up to date equipment and operating methods.

The response of a dosimeter, R, is defined as the result of a measurement under defined conditions, H_m, divided by the conventionally true dose that would be received under those conditions, H_c :

$$R = \frac{H_m}{H_c} \tag{1}$$

The mean response, $\bar{R}$, of a dosimeter under the intended conditions of use may be expressed as a separable function and written as the following product (Hirning and Yuen [7]):

$$\bar{R} = R_0 \bar{r}_1 \bar{r}_2 \ldots \bar{r}_q \ldots \bar{r}_{ij} \ldots \bar{r}_k \bar{r}_l \ldots \bar{\bar{r}}_{uv} \ldots \bar{r}_N \tag{2}$$

where

R_0 = the reference response of a dosimeter. It is the response when all influence quantities are held at reference conditions (normally those conditions under which the dosimeter is calibrated). The overall relative response of a dosimeter, r, is defined as the ratio R/R_0. A relative response, r_q, applicable to an independent influence quantity, q, is defined as the overall relative response of the dosimeter when all influence quantities except q are held at the reference conditions;

N = the number of influence quantities that may affect the response (when two or more influence quantities are not independent, they may be combined into a composite influence quantity, which is independent of other influence quantities);

$\bar{r}_q$ = the mean relative response arising from variations in the values x_q attainable by the q^{th} single independent influence quantity;

$\bar{\bar{r}}_{ij}$ = mean relative response arising from variations in the values x_i and x_j attainable by the i^{th} and j^{th} influence quantities that form a composite independent influence quantity of the first type introduced when the relative response for this composite independent influence quantity, r_{ij} , cannot be separated into independent relative responses r_i and r_j, while the occurrence probability function p_{ij} is separable and expressed as the product of individual probability functions p_i and p_j which are independent of each other;

$\bar{r}_k \bar{r}_l$ = mean relative response arising from variations in the values x_k and x_l attainable by the k^{th} and l^{th} influence quantities that form a composite independent influence quantity of the second type introduced when the relative response for this composite independent influence quantity, r_{kl} , can be separated into independent relative responses

r_k and r_l, while the occurrence probability function p_{ij} is not separable into independent probability functions p_i and p_j;

$\overline{\overline{r}}_{uv}$ = mean relative response arising from variations in values x_u and x_v attainable by the u^{th} and v^{th} influence quantities that form a composite independent influence quantity of the **third type** introduced when neither the relative response r_{uv} nor occurrence probability p_{uv} for this composite independent influence quantity can be separated into individual relative responses, r_u and r_v or independent occurrence probabilities, p_u and p_v.

If the effect of a change in an influence quantity on the relative response is known, and the probability distribution of that influence quantity can be measured or estimated, the mean relative response due to that influence quantity can be calculated using the usual statistical techniques, as follows.

In the case of an independent influence quantity, q, the mean relative response in eqn (2) is expressed as

$$\overline{r}_q = \sum_{s=1}^{M_q} r_{q,s}\, p_{q,s} \tag{3}$$

where

M_q = the number of measured relative responses for the q^{th} influence quantity;

$r_{q,s}$ = is the s^{th} of M_q measured relative responses for the corresponding s^{th} interval in x_q;

$p_{q,s}$ = is the probability that x_q will take on a value in the s^{th} interval.

In the case of a composite influence quantity of the **first type**, the mean relative response is expressed as

$$\overline{\overline{r}}_{ij} = \sum_{s=1}^{M_i} \sum_{t=1}^{M_j} r_{ij,s,t}\, p_{i,s}\, p_{j,t} \tag{4}$$

where $r_{ij,s,t}$ is a response matrix which is dependent on both the i^{th} and j^{th} influence quantities and $p_{i,s}$ and $p_{j,t}$ are occurrence probability vectors that are independent of each other

In the case of a composite influence quantity of the **second type**, the mean relative response is expressed as

$$\overline{r_k r_l} = \sum_{s=1}^{M_k} \sum_{t=1}^{M_l} r_{k,s} r_{l,t} p_{kl,s,t} \tag{5}$$

where $p_{kl,s\,t}$ is an occurrence probability matrix which is dependent on the k^{th} and l^{th} influence quantities, and $r_{k\,s}$ and $r_{l\,t}$ are relative response vectors that are independent of each other

In the case of a composite influence quantity of the **third type**, the mean relative response is expressed as

$$\overline{\overline{r}}_{uv} = \sum_{s=1}^{M_u} \sum_{t=1}^{M_v} r_{uv;s,t} p_{uv;s,t} \tag{6}$$

where $r_{uv;s,t}$ and $p_{uv;s,t}$ are relative response and occurrence probability matrices respectively, which are both dependent on influence quantities u and v

The probabilities are normalized such that

$$\sum_{s=1}^{M_i} p_{i,s} = 1 \qquad \text{and} \qquad \sum_{t=1}^{M_j} p_{j,t} = 1$$

and

$$\sum_{s=1}^{M_k} \sum_{t=1}^{M_l} p_{kl,s,t} = 1 \quad \text{and} \qquad \sum_{s=1}^{M_u} \sum_{t=1}^{M_v} p_{uv,s,t} = 1$$

In the special case where all values of x_i within the range of possible values $[x_i^{min}, x_i^{max}]$ are equally likely, the probability is just equal to the width of the interval, $\Delta x_{i,s}$, divided by width of the range

$$p_{i,s} = \frac{\Delta x_{i,s}}{x_i^{max} - x_i^{min}} \tag{7}$$

Probabilities may also be estimated in this way when information on the actual probabilities is unavailable.

The variance, u^2, of measured responses about the mean response can also be calculated with the usual statistical techniques, and its positive square-root yields the standard uncertainty in the dosimeter response, u. The general expression for the variance in the response is

$$u^2 = R_0^2 \overline{r_1^2} \overline{r_2^2} \cdots \overline{r_q^2} \cdots \overline{r_{ij}^2} \cdots \overline{r_k^2} \overline{r_l^2} \cdots \overline{\overline{r_{uv}^2}} \cdots \overline{r_N^2} - (\overline{R})^2 \tag{8}$$

In this equation, the factors related to relative responses that depend on single influence quantities are given by

$$\overline{r_q^2} = \sum_{s=1}^{M_q} r_{q,s}^2 p_{q,s} \tag{9}$$

The term(s) in eqn (8) involving composite influence quantities of the first type become

$$\overline{r_{ij}^2} = \sum_{s=1}^{M_i}\sum_{t=1}^{M_j} r_{ij,st}^2 p_{i,s} p_{j,t} \tag{10}$$

Similarly, the second type of composite term in eqn (8) is

$$\overline{r_k^2 r_l^2} = \sum_{s=1}^{M_k}\sum_{t=1}^{M_l} r_{k,s}^2 r_{l,t}^2 p_{kl,st} \tag{11}$$

and, for the third type of composite term in eqn (8)

$$\overline{\overline{r_{uv}^2}} = \sum_{s=1}^{M_u}\sum_{t=1}^{M_v} r_{uv,st}^2 p_{uv,st} \tag{12}$$

In addition to the standard uncertainty in the response, there will be a statistical relative uncertainty, u_s, arising from random errors in the measurement process. The size of this uncertainty is determined using a type A evaluation (ISO *Guide to the expression of uncertainty in measurement* [6]). The combined standard uncertainty in a single dose measurement is

$$u_c = \overline{R}\sqrt{\left(\frac{u}{\overline{R}}\right)^2 + u_s^2} \tag{13}$$

Using these definitions, the overall specification for accuracy and precision is given by the following expression:

$$\frac{I}{\rho} \le \overline{R} \pm 2u_c \le \rho \tag{14}$$

where

ρ	=	1.5	for d = 10 mm and 4 mSv $\le H_{p,c}(10) \le$ 10 Sv
=		2	for d = 10 mm and $H_{p,c}(10)$ = 0.4 mSv
=		1.5	for d = 0.07 mm and 100 mSv $\le H_{p,c}(0.07) \le$ 10 Sv
=		2	for d = 0.07 mm and $H_{p,c}(0.07)$ = 10 mSv
=		3	for 100 mSv < He,c < 10 Sv
=		3	for $H_{c,c}$ = 10 mSv

The combined standard uncertainty u_c is multiplied by a coverage factor of 2 to give an uncertainty interval for individual measurements of R corresponding to a level of confidence of approximately 95%. Section A.4A provides a practical example of the calculation described above.

A.4. EXAMPLE CALCULATIONS

A.4.1 Introduction

In analyzing dosimeter response uncertainty, one should first decide upon a number, N, of influence quantities to be considered. These should be influence quantities that would affect the dosimeter response significantly, such as energy, angle of incidence, temperature, humidity, etc. Each influence quantity should be treated as a statistical variable, and is denoted by

x_i where $i = 1,2, \ldots, N$

For example, x_2 denotes all the values between a lower bound and an upper bound that influence quantity number 2 can take on; in short, the influence quantity number 2. Next, one should group the N influence quantities into single, first-type composite, second-type composite, or third-type composite independent influence quantities, so that the dosimeter response becomes a separable function of these independent influence quantities and expressible as a product of relative responses. The conditions for separability are satisfied if, for each grouped independent influence quantity, the fractional change in the overall relative response at conditions other than the reference conditions (see the Glossary) arising from a change in the grouped influence quantity is independent of other grouped influence quantities (Hirning and Yuen [7] - Appendix).

A single independent influence quantity, x_s, consists of only one influence quantity such that the above condition of overall-relative-response separability is satisfied. The dose linearity of a thermoluminescence dosimeter (TLD) is an example of a single independent influence quantity. In this example, the response of a TLD tends to increase as the absorbed dose in the dosimeter increases to a high value in the order of grays. The increase in the dosimeter response does not depend on what photon source (photon energy) has delivered the absorbed dose or any other influence quantities.

A composite influence quantity comprises a subset of the N influence quantities being considered such that, as analogous to a single independent influence quantity, the fractional change in the overall relative response depends only on this independent composite influence quantity alone.

A first-type composite influence quantity consists of influence quantities x_i and x_j (can be extended to more than two). The relative response as a function of x_i and x_j is not separable and therefore, in discrete form, consists of a matrix whose elements are linearly independent of one another. The occurrence probability p_{ij}, however, can be separable into independent probability functions p_i and p_j. An example of a first-type composite influence quantity is given by the combination of photon energy and angle of incidence (i.e., "energy-angle" or "E-θ"). Energy-angle is a first-type composite influence quantity because the dosimeter relative response depends on both the energy and angle and is not

separable. Therefore, the relative response, in discrete form, must be expressed as a two-dimensional matrix, $r_{E\theta}$, whose elements are linearly independent of one another. The occurrence probability function, however, is separable into two independent probability functions p_E and p_θ, as energy and angle are not correlated.

A second-type composite influence quantity consists of influence quantities x_k and x_l. The dosimeter relative response function is separable and therefore, in discrete form, consists of two independent vectors (as opposed to a matrix), each of which is dependent on only one influence quantity, x_k or x_l. The occurrence probability function p_{kl}, however, cannot be separated. An example for a second-type composite influence quantity is humidity-temperature or *H-T*. The dosimeter relative response is separable into two independent relative response functions r_H and r_T because the fractional change of the relative response due to the change in either influence quantity is independent of each other. The occurrence probability function, however, is not separable because relative humidity depends on temperature and, in discrete form, is denoted by a matrix p_{HT}.

A third-type composite influence quantity consists of influence quantities x_u and x_v, such that neither the relative response, r_{uv}, nor the occurrence probability function, p_{uv}, is separable. Thus, in discrete form, each of r_{uv} and p_{uv} consists of a two-dimensional matrix whose the elements are linearly independent of one another. No example is given here, however, because it is very rare to encounter such a composite influence quantity in external dosimetry.

The following section provides an example calculation.

A.4.2 Calculations

This section gives an example of the calculation of mean response and combined standard uncertainty, using hypothetical data. For simplicity, only five influence quantities are assumed to significantly affect the response of the dosimeter, and only photon fields will be addressed. The five influence quantities are photon energy, photon angle of incidence, relative humidity, temperature and dose (dose linearity in dosimeter). The five influence quantities are grouped into one single (dose), one first-type composite (energy-angle) and one second-type composite (humidity-temperature), independent grouped influence quantities. It is assumed that the dosimeter will be used in the environment of a nuclear generating station.

A.4.2.1 Photon Energy and Angle of Incidence

The first step is to measure the relative response for a range of energies and angles that is representative of those expected to be present in the station, while maintaining all other influence quantities at the reference values. The results form the array r_{uv} or $r_{E\theta}$ as shown in Table A.1.

Table A.1 - Hypothetical Measured Relative Response , $r_{E\theta,s,t}$, as a Function of Photon Energy and Angle of Incidence, with Reference to the ^{137}Cs Gamma Ray Response at 0 Degrees

Energy (E)		Angle (θ)				
		Index, t				
		1	2	3	4	5
		Value (deg)				
Index, s	Value (keV)	0	20	40	60	80
1	33	0.85	0.84	0.82	0.80	0.75
2	48	0.97	0.97	0.96	0.94	0.89
3	65	1.08	1.08	1.07	1.05	1.00
4	83	1.16	1.16	1.15	1.13	1.09
5	100	1.14	1.14	1.13	1.12	1.08
6	118	1.10	1.10	1.10	1.09	1.05
7	164	1.08	1.08	1.08	1.07	1.03
8	208	1.05	1.05	1.05	1.04	1.00
9	250	1.02	1.02	1.02	1.01	0.98
10	662	1.00	1.00	1.00	0.99	0.96
11	1250	0.95	0.95	0.95	0.94	0.92

Next, intervals of energy and angle are defined about each of the measurement points, and the probability of exposure in each interval is estimated. Tables A.2 and A.3 show the results. Although it is possible that the energy and angle of incidence will be correlated for a particular location and orientation, the averaging effect of moving about in the field will greatly reduce any correlation, and the two influence quantities can be treated as uncorrelated.

Table A.2 - Energy Intervals and Assumed Probability, $p_{E,s}$, of Receiving Dose in Each

Index, s	E (keV)	Interval (keV)	Probability $p_{E,s}$
1	33	0-40	0.01
2	48	41-55	0.01
3	65	56-74	0.03
4	83	75-91	0.05
5	100	92-109	0.05

6	118	110-141	0.05
7	164	142-186	0.05
8	208	187-229	0.05
9	250	230-450	0.25
10	662	451-950	0.30
11	1250	951-1500	0.15
		Sum	1.00

Table A.3 - Angle of Incidence Intervals and Assumed Probability, $p_{\theta,t}$, of Receiving Dose in Each

Index, t	θ (deg)	Interval (deg.)	Probability $p_{\theta,t}$
1	0	0-10	0.20
2	20	11-30	0.30
3	40	31-50	0.30
4	60	51-70	0.10
5	80	71-90	0.10
		Sum	1.00

The mean relative response for photon energy-angle is given by eqn (4)[2], and may be calculated from the relative responses in Table A.1 and the probability distributions in Tables A.2 and A.3 using matrix multiplication. By substituting E for i, θ for j, 11 for M_i and 5 for M_j, eqn (4) becomes

$$\overline{r_{E\theta}} = \sum_{s=1}^{s=11} \sum_{t=1}^{t=5} r_{E\theta,st}\, p_{E,s}\, p_{\theta,t} \qquad (4A)$$

yielding

$$\overline{r_{E\theta}} = 1.018$$

Similarly, after squaring the elements of the response matrix, eqn (10) becomes

$$\overline{r^2_{E\theta}} = \sum_{s=1}^{s=11} \sum_{t=1}^{t=5} r^2_{E\theta,st}\, p_{E,s}\, p_{\theta,t} \qquad (10A)$$

[2] The equations referred to in this section are found in section A.3 of this appendix.

1) and gives

$$\overline{r_{E\theta}^2} = 1.041$$

A.4.2.2 Relative Humidity and Temperature

Since these two influence quantities are assumed to affect the dosimeter response independently, the relative responses can be measured for a series of values for each quantity, while maintaining the other at its reference value. Again, intervals are defined about each of the measured values, so that the full range of interest is covered. Tables A.4 and A.5 give the measurement points, the corresponding intervals and relative responses.

Table A.4 – Measured Relative Response, $r_{H,s}$, as a Function of Relative Humidity, H, with Reference Value of 50%

Index, s	H (%)	Interval (%)	Relative Response $r_{H,s}$
1	40	0-50	1.00
2	60	51-70	0.99
3	80	71-90	0.98
4	95	91-100	0.95

Table A.5 - Measured Relative Response $r_{T,t}$, as a Function of Temperature T, with Reference Value of 20°C

Index, t	T °C	Interval °C	Relative Response $r_{T,t}$
1	-10	(-15)-(-5)	1.05
2	0	(-6)-(5)	1.03
3	10	6-15	1.01
4	20	16-25	1.00
5	30	26-35	0.99
6	40	36-45	0.95
7	50	46-55	0.90

Since temperature and relative humidity are correlated in the workplace environment, a probability matrix, p_{HT}, is estimated as shown in Table A.6.

Table A.6 - Assumed Relative Probability of Occurrence, $p_{HT,s,t}$, in the Workplace of Each Combination of Temperature and Relative Humidity Interval

		Temperature							
		Index, t							
		1	2	3	4	5	6	7	
Humidity		Interval (°C)							
Index, s	Interval (%)	(-15)-(-5)	(-6)-(5)	6-15	16-25	26-35	36-45	46-55	Sum
1	0-50	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.04
2	51-70	0.00	0.00	0.11	0.30	0.05	0.00	0.00	0.46
3	71-90	0.00	0.00	0.00	0.25	0.15	0.03	0.00	0.43
4	91-100	0.00	0.00	0.00	0.00	0.05	0.01	0.01	0.07
									1.00

Substituting H for k, T for l, 4 for M_k, and 7 for M_l eqn (5) becomes

$$\overline{r_H r_T} = \sum_{s=1}^{s=4}\sum_{t=1}^{t=7} r_{H,s} r_{T,t} p_{HT,s,t} \qquad (5A)$$

2) yielding

$$\overline{r_H r_T} = 0.980$$

Similarly, eqn (11) becomes

$$\overline{r_H^2 r_T^2} = \sum_{s=1}^{s=4}\sum_{t=1}^{t=7} r_{H,s}^2 r_{T,t}^2 p_{HT,s,t} \qquad (11A)$$

3) resulting in

$$\overline{r_T^2 r_H^2} = 0.961$$

A.4.2.3 Dose Linearity

In this simpler case of a single independent influence quantity, the relative responses, r_q, and corresponding probabilities of occurrence, p_q, can be represented in the form of independent vectors as shown in Table A.7.

Table A.7 - Measured Relative Response, $r_{D,s}$, to Increasing Dose (linearity) and the Assumed Probability $p_{D,s}$, of Receiving Dose in Each Interval

(The reference value is 10 mSv)				
Index, s	**Dose, D (mSv)**	**Range, q (mSv)**	**Relative Response $r_{D,s}$**	**Probability $p_{D,s}$**
1	0.1	0-0.2	1.05	0.900
2	0.5	0.2-0.7	1.02	0.050
3	1.0	0.7-2.0	1.00	0.030
4	5.0	2.0-7.0	1.00	0.010
5	10	7-20	1.00	0.009
6	50	20-70	1.00	0.001
7	100	70-200	1.00	0.000
8	500	200-700	1.00	0.000
9	1000	700-1500	1.02	0.000
10	2000	1500-3000	1.05	0.000
11	4000	3000-5000	1.08	0.000
12	6000	5000-7000	1.11	0.000
13	8000	7000-9000	1.15	0.000
14	10000	9000-11000	1.20	0.000
				1.000

In this case, by substituting D for q and 14 for M_s, eqn (3) becomes

$$\bar{r}_D = \sum_{s=1}^{s=14} r_{D,s} p_{D,s} \qquad (3A)$$

yielding

$$\overline{r_D} = 1.046$$

Similarly, eqn (9) becomes

$$\overline{r_D^2} = \sum_{s=1}^{s=14} r_{D,s}^2 p_{D,s} \qquad (9A)$$

resulting in

$$\overline{r_D^2} = 1.094$$

A.4.2.5 Mean Response and Combined Uncertainty

If the dosimeter has been calibrated to give the conventionally true value of the dose at the reference conditions, then $R_o = 1$. Eqn (2) can now be expressed as

$$\overline{R} = 1 * \overline{r_D} * \overline{r_{E\theta}} * \overline{r_H r_T} \qquad (2A)$$

Using this value and the results of preceding sections in eqn (2A) gives a mean response of

$$\overline{R} = 1.044$$

The variance in the response is given by eqn (8) which can be rewritten as

$$u^2 = 1^2 * \overline{r_D^2} * \overline{r_{E\theta}^2} * \overline{r_H^2 r_T^2} - (\overline{R})^2 \qquad (8A)$$

resulting in

$$u^2 = 0.0045$$

A series of replicated measurements at doses greater than 4 mSv, with all of the five influence quantities held constant at the reference conditions, shows a statistical relative uncertainty, u_r, of 10%. This can be taken as the Type A assessment of uncertainty due to random errors.

Combining the standard uncertainty in the response with the statistical relative uncertainty according to eqn (13) leads to the combined standard uncertainty in a single measurement

$$u_c = 1.044 \sqrt{\frac{0.0045}{(1.044)^2} + (0.1)^2}$$
$$= 0.124$$

The upper and lower limits defined by eqn (14) are then (0.80, 1.29), which lie well within the required limits of (0.67, 1.5) corresponding to $\rho = 1.5$.

At 0.4 mSv, where the requirement is given by $\rho = 2$, the mean relative response and the uncertainty in the response are likely to be the same as at higher doses. The uncertainty arising from random errors is the component of the overall uncertainty that is likely to increase, and must be separately determined at this lower dose.

APPENDIX B
TYPE TEST SPECIFICATIONS FOR EXTERNAL DOSIMETRY

B.1 INTRODUCTION

In addition to the in-house quality assurance program described in section 5.0, section 4.1.4 describes a requirement for type testing. If dosimeters in routine use may be exposed to conditions other than those mentioned here, but that may influence the result of a dose measurement, such conditions must be identified and included in the type tests, in addition to those listed below.

Wherever possible, an error introduced by an influence quantity should be corrected by applying a correction factor to the calculation of H_m (the result of a measurement under defined conditions) with the objective of making the mean relative response for that influence quantity close to unity. Circumstances may exist, however, in which it is impractical or undesirable to apply a correction for a particular influence quantity. In such cases, the error introduced by the influence quantity will be included in the determination of the mean response.

B.2 INFLUENCE QUANTITIES AND SYSTEM CHARACTERISTICS

The dosimetry service shall consider the following influence quantities and evaluate those that are likely to significantly affect accuracy or uncertainty. In deciding on the potential significance of the influence quantities, both the design of the dosimetry system and the intended conditions of use must be taken into account.

1. angle of incidence of radiation;
2. distance of dosimeter from phantom;
3. dose (i.e., linearity of dose response);
4. dose rate, including in pulsed radiation fields;
5. electrical and magnetic fields, both static and alternating;
6. energy of photons and beta rays;
7. humidity and splashing;
8. ionizing radiations other than those intended to be measured;
9. mechanical shock, both dropping and vibration of the dosimeter;
10. mixed radiation fields;
11. temperature variations, both gradual and abrupt;
12. time between zeroing and irradiation, and between irradiation and reading;
13. visible and ultraviolet light flux (effect on both dosimeter and reader); and
14. voltage supply to reader, both voltage spikes and gradual variations.

In addition, the dosimetry service shall estimate the effects of the following system characteristics, as applicable:

1. batch homogeneity,
2. calibration uncertainty,
3. repeatability (a measure of the stability of response of both the dosimeter and the reader),
4. residual signal,
5. self irradiation, and
6. zero-dose variations.

Where an influence quantity or system characteristic causes a large and sudden change in the measured dose, but has a low probability of occurring, it is not appropriate to include that change as a component of the combined standard uncertainty. Instead, steps shall be taken to minimize the probability that the influence quantity will cause the effect, either by changing the dosimeter design or by instituting procedural controls, and estimating the reduced probability of occurrence.

B.3 PHANTOMS

During irradiation, dosimeters must be mounted on an appropriate phantom for type tests of the following influence quantities: angle of incidence of radiation, distance of dosimeter from phantom, and energy of photons and beta rays. For tests of other influence quantities requiring irradiation, any convenient irradiation geometry may be used, provided that the relative doses delivered to the dosimeters are known to the degree of accuracy appropriate to the test. The signal produced by the dosimeters in these tests can be related to the corresponding conventionally true dose using the results of the on-phantom irradiations.

For dosimeters to be worn during torso (whole-body) irradiations, the phantom to be used for photon irradiations is a parallelepiped ("slab"), constructed of polymethylmethacrylate (PMMA) walls and filled with water (ISO 4037-3 [9]). The external dimensions are 30 cm x 30 cm x 15 cm, and the wall thicknesses are 2.5 mm for the front wall (one of the 30 cm x 30 cm faces) and 10 mm for the other five walls. The phantom shall be constructed in a way that ensures that the front face remains flat when the phantom is filled with water. For beta irradiations, the phantom to be used may be the same water-filled slab phantom as described above. A solid PMMA slab phantom of the same face dimensions and a thickness greater than one-half of the range of the most energetic beta particles may also be used.

For extremity dosimeters, the phantoms to be used must be radiologically suitable representations of the appropriate parts of the extremities where the dosimeters will be worn. These will usually be the fingers, the wrists and the ankles. The phantoms to be used shall be appropriate to both the dosimeter design and the radiological environment

in which they will be used. Two possible phantoms for use are indicated below. The dosimetry service shall consult CNSC prior to using other phantoms.

finger: solid PMMA cylinder with a 19 mm diameter and a length of 300 mm (Roberson [10]; Grosswendt [11], [12], [13]; ISO 12794[14]).

wrist/ankle: water-filled PMMA cylinder with an outer diameter of 73 mm, a wall thickness 2.5 mm and a length of 300 mm (ISO 12794[14]).

The references include the associated air-kerma to dose conversion coefficients. More recent references containing more up-to-date information may also be used as they become available. However, the dosimetry service shall consult CNSC prior to using other references.

B.4 ANGLE OF INCIDENCE OF RADIATION

For dosimeters that are irradiated on the slab phantom described above, the test radiations shall be incident on the front face of the dosimeter at angles of 0°, ±20°, ±40° and ±60°, relative to normal incidence. If the design of the dosimeter results in an angular response that is cylindrically symmetric about the axis perpendicular to its front face, it will be sufficient to make the measurements along only one direction in one plane (*i.e.*, 4 measurements will be required). If cylindrical symmetry does not apply, the measurements may required in both directions in two perpendicular planes (i.e., up to 13 measurements may be required) to adequately characterize the angular response of the dosimeter. In the latter case, the average response for each angle is calculated and indicated as the response for that angle.

For extremity dosimeters, the test radiations shall be incident on the front face of the dosimeter at angles of 0°, 20°, 40°, and 60° relative to normal incidence in two perpendicular planes (i.e., a minimum of 7 measurements will be required; if the dosimeter is not cylindrically symmetrical, 13 measurements may be required). The average response for each angle is calculated and indicated as the response for that angle.

B.5 PHOTON ENERGIES

For all types of dosimeters, the photon energies used for the test irradiations shall conform to the International Standard ISO 4037-1 [15]. Coefficients to convert from exposure or air kerma to $H_{p,x}(d)$ have been calculated and published for these energy spectra (see ISO 4037-3 [9]). The calculations are based on a slab phantom made from the International Commission on Radiation Units and Measurements (ICRU) standard tissue, of the same dimensions as the water-filled phantom described above. The difference in backscatter between the ICRU tissue phantom and the water-filled phantom is small enough that it can be neglected. Coefficients to convert from air kerma to $H_{e,x}$ on cylindrical phantoms have been calculated and published (ISO 12794 [14]). A need may exist to add build-up material in front of the dosimeter for higher photon energies for $H_{p,x}(0.07)$ and $H_{e,x}$ to ensure charged particle equilibrium.

B.6 BETA ENERGIES

The standard beta sources listed in Table B.1 shall be used for type testing of dosimeters intended to measure $H_p(0.07)$ and H_c

Table B.1 - Standard Beta Sources

Isotope	Maximum Beta Energy (keV)
$^{90}Sr/^{90}Y$	2274
^{85}Kr or ^{204}Tl	763 or 687
^{147}Pm	225

Note that for intermediate beta energies, either ^{85}Kr or ^{204}Tl must be used. ISO 6980 [16] provides further information about these sources, except for ^{85}Kr. The source manufacturer will provide information for ^{85}Kr. These sources are commercially available with traceable calibrations for irradiation at normal incidence. For extremity dosimeters irradiated at off-normal angles of incidence, the angular dependence factors for a tissue equivalent slab phantom may be used. The conversion coefficients normalized to 0° for $H_p(0.07)$ at other angles of incidence have been published (see, *e.g.*, European Community Report EUR 14852 EN [17]).

The accurate measurement of $H_p(0.07)$ and H_c for beta radiation becomes increasingly difficult as the beta energy decreases and the angle of incidence increases. The overall specification in section 4.1.2 and Table 1 will, therefore, be applied as follows:

For $^{90}Sr/^{90}Y$ beta radiation:
The specification must be met at all angles of incidence specified in section B.4. of this appendix.

For ^{85}Kr or ^{204}Tl beta radiation:
The specification must be met only at 0°, and the response measured at the other angles specified in section B.4. of this appendix.

For ^{147}Pm beta radiation:
The response must be measured at the angles specified in section B.4. of this appendix.

The mean relative responses and standard uncertainties for photons and betas are determined separately for comparison with the specifications defined by eqn (14) in section A.3 of APPENDIX A.

APPENDIX C
INDEPENDENT TEST SPECIFICATIONS FOR EXTERNAL PHOTON DOSIMETRY

C.1 Introduction

In addition to the in-house quality assurance program described in section 5.0, section 4.1.6 describes a requirement for independent testing.

Dosimetry services that are ready to undergo independent testing shall make arrangements directly with the relevant reference calibration centre (see APPENDIX J). Dosimetry services using dosimeters that require processing (e.g., TLDs) shall follow the protocol outlined in section C.2. Dosimetry services using dosimeters that do not require processing (e.g., electronic dosimeters) shall follow the protocol outlined in section C.3, below. Although section C.3 describes the use of air kerma units specifically, corresponding exposure units may also be used, if preferred by the dosimetry service, in consultation with the reference calibration centre.

C.2 Protocol for Dosimeters That Require Processing

1) Where necessary, a dosimetry service must determine a factor to convert from $H_p(10)$, as measured by the dosimeters on a phantom, to air kerma free-in-air (or exposure free-in-air) due to ^{60}Co gamma radiation. This is necessary since the irradiations performed at the reference calibration centre are free-in-air.

2) Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, each dosimetry service shall send to the relevant calibration centre at least 50 identified dosimeters per processing unit being tested plus sufficient control dosimeters to satisfy the readout process. For each unit being tested, the calibration centre will divide the submitted dosimeters into at least 10 groups of at least five dosimeters per group and irradiate each group of dosimeters, free in air, in a ^{60}Co photon beam to a different but known air kerma between 1.0 mGy and 50 mGy. The air kerma delivered to the dosimeters will not be revealed at this time to the dosimetry service.

3) The irradiated dosimeters and controls will be returned to the dosimetry service for processing by the established routine procedures of the service. The results in air kerma units, adjusted as necessary using the factor determined in (1), above, will be reported to the reference calibration centre by the dosimetry service.

4) The reference calibration centre will compare the reported results with its values of air kerma. The results (giving both the service's and the reference calibration centre's values) will be reported to the CNSC by the reference calibration centre, with a copy sent to the dosimetry service. In order to pass this test, the reported results must lie within the criteria described in section 4.1.6.

C.3 Protocol for Dosimeters That Do Not Require Processing

1) Where necessary, a dosimetry service using dosimeters that do not require processing must determine a factor to convert from $H_p(10)$, as measured by the dosimeters on a phantom, to air kerma free-in-air (or exposure free-in-air) due to ^{60}Co gamma radiation. This is necessary since the irradiations performed at the reference calibration centre are free-in-air.

2) Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, each dosimetry service shall send at least 10 identified dosimeters to the reference calibration centre. The reference calibration centre will irradiate at least 10 groups of at least 5 dosimeters each, free in air, in a ^{60}Co photon beam to different but known air kermas of between 1.0 mGy and 50 mGy. The dosimeters in each group of five will either be exposed to the same air kerma or to different air kermas but within a similar range. This will result in a total of at least 50 readings that will be recorded by the reference calibration centre. In view of the number of dosimeters involved in this case, any given dosimeter may be irradiated several times.

3) The reference calibration centre will correct the dosimeter readings using the conversion factors determined in (1) above and compare the results with the reference calibration centre values air kerma. The results (giving both the participant's and the reference calibration centre's values) will be reported to the CNSC at the address below by the reference calibration centre, with a copy sent to the dosimetry service. The dosimeters will be returned to the dosimetry service upon completion of all irradiations. In order to pass this test, reported results must lie within the criteria described in section 4.1.6.

C.4 Reporting

The reference calibration centre reports the results to the CNSC at the following address:

Dosimetry Services Licensing Specialist
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
Ottawa, ON K1P 5S9
CANADA

Further details on these tests may be obtained from the reference calibration centre.

APPENDIX D
INDEPENDENT TEST SPECIFICATIONS FOR EXTREMITY DOSIMETRY

D.1 Introduction

In addition to the in-house quality assurance program described in section 5.0, section 4.1.6 describes a requirement for independent testing.

Dosimetry services that are ready to undergo independent testing shall make arrangements directly with the relevant reference calibration centre (see APPENDIX J). Dosimetry services using dosimeters that require processing (e.g., TLDs) shall follow the protocol outlined in section D.2. Dosimetry services using dosimeters that do not require processing (e.g., electronic dosimeters) shall follow the protocol outlined in section D.3.

D.2 Protocol for Dosimeters That Require Processing

1) Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, each dosimetry service shall send to the reference calibration centre at least 25 identified extremity dosimeters per processing unit being tested plus sufficient control dosimeters to satisfy the readout process. For each unit being tested, the reference calibration centre will divide the submitted dosimeters into at least 5 groups of at least 5 dosimeters per group and irradiate each group of dosimeters to a known absorbed dose to soft tissue of between 10 mGy and 90.0 mGy at a depth of 7 mg/cm^2 using its ^{90}Sr-^{90}Y source. The doses delivered to the dosimeters will not be revealed at this time to the dosimetry service.

2) The irradiated dosimeters and controls are returned to the dosimetry service for processing by the established routine procedures of the service. The dosimetry service reports the results in absorbed dose units to the reference calibration centre.

3) The reference calibration centre will compare the reported doses with those that were given to the dosimeters. The results (giving both the service's and the reference calibration centre's values) will be reported to the CNSC (see address below) by the reference calibration centre, with a copy sent to the dosimetry service. In order to pass this test, the reported results must lie within the criteria described in section 4.1.6.

D.3 Protocol for Dosimeters That Do Not Require Processing

1) Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, each dosimetry service shall send at least 10 identified dosimeters to the reference calibration centre. The reference calibration centre will irradiate them to different but known absorbed doses to soft tissue of between 10 mGy and 90.0 mGy at a depth of 7 mg/cm^2 using its ^{90}Sr-^{90}Y source.

2) The reference calibration centre will compare the results with the doses to which the dosimeters were irradiated. The results (giving both the participant's and the reference calibration centre's values) will be submitted to the CNSC at the address below by the reference calibration centre, with a copy sent to the dosimetry service. The dosimeters will be returned to the dosimetry service upon completion of all irradiations. In order to pass this test, reported results within the accuracy described in section 4.1.6 are required.

D.4 Reporting

The reference calibration centre reports the test results to the CNSC at the following address:

Dosimetry Services Licensing Specialist
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
Ottawa, ON K1P 5S9
CANADA

Further details on these tests may be obtained from reference calibration centre.

APPENDIX E
INDEPENDENT TEST SPECIFICATIONS FOR NEUTRON DOSIMETRY

E.1 Introduction

In addition to the in-house quality assurance program described in section 5.0, section 4.1.7.1 describes a requirement for independent testing.

Dosimetry services that are ready to undergo independent testing shall make arrangements directly with the reference calibration centre. Dosimetry services using dosimeters that require processing (e.g., solid state nuclear track detectors) shall follow the protocol outlined in section E.2. Dosimetry services using dosimeters that do not require processing (e.g., electronic dosimeters) shall follow the protocol outlined in section E.3.

E.2 Protocol for Personal Dosimeters That Require Processing

1) Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, each dosimetry service shall send to the reference calibration centre at least 10 identified dosimeters plus sufficient control dosimeters to satisfy the readout process. The reference calibration centre will divide the submitted dosimeters into 2 groups of at least 5 dosimeters per group and irradiate each group of dosimeters in an ^{241}Am-Be neutron field to a different but known value of $H_p(10)$ due to neutrons of between 1 mSv and 10 mSv. The delivered values will not be revealed at this time to the dosimetry service.

2) The irradiated dosimeters and controls will be returned to the dosimetry service for processing by the established routine procedures of the service. The dosimetry service reports the results to the reference calibration centre.

3) The reference calibration centre will compare the reported results with its values. The results (giving both the service's and the reference calibration centre's values) will be submitted to the CNSC at the address below by the reference calibration centre, with a copy sent to the dosimetry service. In order to pass this test, the reported results must lie within the criteria described in section 4.1.7.

E.3 Protocol for Personal Dosimeters That Do Not Require Processing

1) Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, each dosimetry service shall send a representative sample of identified dosimeters to the reference calibration centre. The reference calibration centre will irradiate them in an Am-Be neutron field to two different but known values of $H_p(10)$ due to neutrons of between 1 mSv and 10 mSv.

2) The reference calibration centre will compare the readings with its values. The results (giving both the participant's and the reference calibration centre's values) will be submitted to the CNSC at the address below by the reference calibration centre, with a copy sent to the dosimetry service. The dosimeters will be returned to the dosimetry service upon completion of all irradiations. In order to pass this test, reported results must lie within the criteria described in section 4.1.7.

E.4 Reporting

The reference calibration centre reports the test results to the CNSC at the following address:

Dosimetry Services Licensing Specialist
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
Ottawa, ON K1P 5S9
CANADA

Further details on these tests may be obtained from the reference calibration centre.

APPENDIX F
INDEPENDENT TEST SPECIFICATIONS FOR INTERNAL DOSIMETRY

F.1 Introduction

In addition to the in-house quality assurance program described in section 5.0, sections 4.2.4 and 4.2.6 describe requirements for independent testing.

Dosimetry services shall make arrangements for participating in these independent tests directly with the relevant reference calibration centre.

Upon completion of the testing and analysis of the results, the reference calibration centre submits a report containing the identity of each participating dosimetry service and its corresponding performance results to the CNSC. When the reference calibration centre becomes aware that a licensed internal dosimetry service has failed an independent test, it informs the CNSC. The reference calibration centre also submits to each participating laboratory a report of the test results in which the identities of the laboratories are represented by a code.

F.2 *In Vitro* Measurement Independent Tests

Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, or other interval as determined in consultation with the CNSC, the reference calibration centre supplies each participating laboratory with appropriate samples and blanks. Dosimetry services participate for the applicable radionuclides. The dosimetry service analyzes the samples according to a schedule furnished by the reference calibration centre. Results are entered on a standard reporting form and returned to the reference calibration centre. When all laboratories have responded, the reference calibration centre analyzes the results and issues a report, with each laboratory identified only by a code letter. The reference calibration centre informs each laboratory of its own code letter and informs the CNSC of all the dosimetry services' (licensees and applicants) code letters.

Further details of the independent tests and the method of analysis may be obtained from the reference calibration centre. Dosimetry services must participate in these independent tests and obtain passing results prior to being granted a dosimetry service licence by the CNSC, and at least once per year thereafter in order to demonstrate continuing capability. The procedure must be repeated if the measurement method or equipment undergo any changes.

F.3 *In Vivo* Measurement Independent Tests

The reference calibration centre has tissue equivalent phantoms available for a variety of radionuclides in the lung, ^{125}I and ^{131}I thyroid neck phantoms, and water-filled BOMAB phantoms of varying size for higher photon energies.

Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, or other interval as determined in consultation with the CNSC, the dosimetry service must undergo independent testing in order to demonstrate continuing capability. If the measurement method or equipment undergo any significant changes after a dosimetry service licence has been granted and prior to implementing the new measurement method or putting the equipment back into service, the affected bioassay method and equipment must pass an independent test. Significant changes to the measurement method or equipment can only be implemented by the licensee once the report has been approved by the CNSC.

The independent tests for *in vivo* bioassay will be designed so that:

1) The radionuclide mixtures for measurement in phantoms are limited to three radionuclides, excluding ^{40}K.

2) The location of the activity in the phantoms is realistic (e.g., in the lungs or gastrointestinal region).

3) The radionuclides used in *in vivo* testing vary from one test to another.

4) The water-filled BOMAB phantoms that are used for *in vivo* testing all contain ^{40}K and include

   reference female

   5th percentile male

   reference male

   95th percentile male.

Also, in order to be representative of the workplace, overlay plates may be used in the *in vivo* tests.

F.4 Performance tests for ascertaining the committed effective dose

Prior to licensing and subsequently at regular intervals with a frequency of at least once every 12 months, or other interval as determined in consultation with the CNSC, the reference calibration centre supplies each participating laboratory with relevant hypothetical exposure scenarios. The dosimetry service assesses the committed effective dose from the hypothetical exposure scenarios that are relevant to the activities carried on by CNSC licensees that use the dosimetry service. When all laboratories have responded, the reference calibration centre analyzes the results and issues a report, with each laboratory identified only by a code. The reference calibration

centre informs each laboratory of its own code and informs the CNSC of all the dosimetry services' (licensees and applicants) code.

Further details of the performance test may be obtained from the reference calibration centre. Dosimetry services must participate in these performance tests prior to being granted a dosimetry service licence by the CNSC, and at least once per year thereafter in order to demonstrate continuing capability.

F.5 Reporting

The reference calibration centre reports the tests results to the CNSC at the following address:

Dosimetry Services Licensing Specialist
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
Ottawa, ON K1P 5S9
CANADA

Further details on these tests may be obtained from the reference calibration centre.

APPENDIX G
INDEPENDENT TEST SPECIFICATIONS FOR RADON GAS AND RADON PROGENY

G.1 Introduction

In addition to the in-house quality assurance program described in section 5.0, sections 4.3.5 and 4.3.8 describe requirements for independent testing.

Dosimetry services for radon and radon progeny that are ready to undergo independent testing shall make arrangements for participating in these independent tests directly with the relevant reference calibration centre (see APPENDIX J).

G.2 Protocol for Personal Monitors

The instruments sent shall be clean and uncontaminated, and in working order. The overall performance of a given system shall be such that the accuracy specifications in Table 7 of section 4.3.3 are met for radon progeny and section 4.3.6 for radon gas. The dosimetry service shall contact the reference calibration centre to arrange suitable scheduling before instruments are sent.

G.3 Grab Sampling

Independent testing is also required for dosimetry services that use grab sampling to determine exposures of workers to radon progeny (because personal radon gas monitors are relatively inexpensive and available, grab sampling for radon gas dosimetry is not addressed here). The use of grab sampling for the determination of radon progeny exposures is a staged process that requires the collection of aerosols on a filter over a short time period, the measurement of the radioactivity of the aerosols and a calculation of the potential alpha radiation (working levels (WL), or $\mu J/m^3$) due to the short-lived radon progeny. Calibration procedures are also required for the air sampling train and for the counting system. The determination is complex and sources of error include instrumental sources and variances in the implementation of the collection procedure by the technicians conducting the determination.

A conventional independent testing program to validate the performance of the measurements may be impractical since it would require all measurement systems and the techniques of individual technicians to be verified at the CNSC reference calibration facility on a routine basis. As an alternative, a designated CNSC inspector's qualifications in measuring radon progeny will be verified by the reference calibration centre on an annual basis. Dosimetry services may then have their technicians' performance verified on an annual basis by one of the following two methods:

1) The designated CNSC inspector individually validates all technicians at each dosimetry service; or

2) The CNSC validates a designated technician representing the dosimetry service in the above described method and that technician in turn validates all other technicians on site who conduct radon progeny grab sampling for dosimetry purposes. The results of the validations must be recorded and retained by the dosimetry service.

The validations described above will require a minimum of 10 samples. The differences in the results of the overall performance of the instruments and sampling technicians must be such that the accuracy specifications in Table 8 of section 4.3.3 are met.

G.4 Reporting

The reference calibration centre reports the test results to the CNSC at the following address:

Dosimetry Services Licensing Specialist
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
Ottawa, ON K1P 5S9
CANADA

Questions with respect to direct validation of technicians at the reference calibration centre should be directed to the reference calibration centre.

APPENDIX H
EXAMPLE CALCULATIONS FOR LLRD MEASUREMENTS

H.1 Example Calculation for the Determination of the Minimum Measurable Concentration

The minimum measurable activity concentration in air (MMC) varies with the parameters of the counting system and the volume of the sample. The following equation, derived from Strom and Stansbury [18], is such that the probability of failing to detect the activity concentration is not greater than 5%. Other equations may be acceptable depending upon the situation.

$$MMC = \frac{2.71 + 4.65\sqrt{C_b}}{T_c} * \frac{1}{E * V}$$

where

C_b = the background count of the detector;

Tc = the count time in seconds;

E = the efficiency of the detector in counts per second per Bq;

V = the volume of the sample in m3.

An MMC of 0.05 Bq/m^3 can be achieved through varying the parameters in the equation. For example, if a background count of 250 is used with a total count time of 3600 seconds, a counter efficiency of 0.35 and a volume of 1.2 m^3, then the MMC would be

$$MMC = \frac{2.71 + 4.65\sqrt{250}}{3600} * \frac{1}{0.35 * 1.2}$$

$$= 0.05 \text{ Bq/m}^3$$

which is acceptable.

Note that the volume of the sample is dependent upon both the flow rate of the air sampling pump and the duration of the sample collecting period.

H.2 Example Calculations for Uncertainty

When the difference in count rate, expressed in counts per minute (cpm), is 2 or more, and the total number of counts (sample plus background) is more than 40, the following equations can be used to calculate the limits within which the true (unknown) count lies, 95% of the time (Ballot [19], National Radiological Protection Board NRPB R-113 [20]).

$$Lower\ limit = (C_t - C_b) - 1.96\sqrt{C_t + C_b}$$

$$Upper\ limit = (C_t - C_b) + 1.96\sqrt{C_t + C_b}$$

where

Cb = background count, for the sample counting time;

Ct = total count;

Ct - Cb = net count.

with default ALI for uranium ore dust of 3 190 Bq and consequently a DAC of 1.33 Bq m^{-3}, assuming 2 000 hr of work/year and a breathing rate of 1.2 m^3/hr;

sampling rate of 2.5 L min-1 (2.5 x 10-3 m3 min-1);

duration of sampling of 6 hours;

counting efficiency of 0.4;

background count rate of 1 cpm; and

when the LLRD concentration is 1/10 of the DAC (i.e., 0.133 Bq m^{-3}),

the activity collected on the filter is

0.133 Bq m^{-3} x 2.5 x 10^{-3} m^3 min^{-1} x 60 min h^{-1} x 6 h = 0.120 Bq

and the total count rate (sample plus background) is

1 cpm + (60 s min-1 x 0.120 Bq x 0.4) = 3.87 cpm.

If both the background and the sample are counted for 20 minutes, then the background count is 20, and the sample count (total count) is

20 x 3.87 = 77 (rounded to the nearest integer)

Solving the above equations with the above values (i.e., with $C_b = 20$ and $C_t = 77$), one obtains:

lower limit of the 95% confidence interval: 38;

upper limit of the 95% confidence interval: 76.

Therefore, there is a 95% probability that the true count is larger than 38, and smaller than 76.

Since 57 is the best estimate of the true count, there is a 95% probability that the LLRD concentration measurement lies within - (57 - 38)/57 and + (76 - 57)/57, that is within ± 33%.

APPENDIX I
SPECIFICATIONS FOR DOSE RECORDS

I.1 Introduction

All dosimetry services must submit dose data on a regular basis to the National Dose Registry (NDR) and without undue delay. Operators of such services must ensure that the data to be transmitted to the NDR are in a form compatible with the NDR.

I.2 Individual Identification

An unambiguous individual identification is required; therefore, some redundancy is necessary. The following minimum information is required:

1) SIN (Social Insurance Number);
2) surname/previous surnames;
3) first given name (formal form, not nickname);
4) second given name (formal form, not nickname);
5) sex;
6) date of birth (Year/Month/Day);
7) place of birth (Province, if born in Canada, or country, if born outside Canada); and
8) individual occupational codes or classifications.

I.3 Dose Data

I.3.1 Dose from External Sources

Measurements of $H_p(10)$ shall be reported as effective dose. Measurements of $H_p(0.07)$ shall be reported as equivalent dose to the skin. Measurements of doses to the extremities or the lens of the eye shall be reported as equivalent doses to those tissues.

I.3.2 Dose from Internal Sources

Dose estimates from internal sources other than those given in section 4.3 are to be reported to the NDR by indicating the radionuclide that was taken in and the associated committed effective dose.

I.3.3 Exposures to Radon, Radon Progeny and Intakes of Long-Lived Radioactive Dust

Exposures to radon progeny shall be recorded in working level months (WLM). Doses from intakes of radon and long-lived radioactive dust shall be recorded in millisieverts (mSv).

I.4 Supporting Information

In addition to the dose data, all pertinent data used to generate the dose, exposure or concentration totals shall be retained by the dosimetry service where applicable, such as:

1) readings of personal dosimeters and other data used for measuring external radiation;
2) measurements of organ burdens;
3) estimates of intakes of prescribed substances;
4) method of measurement of concentrations in bioassay samples;
5) chemical forms;
6) dosimetry models used;
7) measurements of radon progeny product concentrations in air; and
8) time spent by individuals in specific locations of a mine.

Any reports made as a result of the investigation of over exposures or other unusual doses shall also be kept.

APPENDIX J
REFERENCE CALIBRATION CENTRES[1]

The CNSC recognizes the following organizations as the reference calibration centres for the type of dosimetry listed.

J.1 Independent Test Specifications for External Photon Dosimetry, Extremity Dosimetry and Neutron Dosimetry

National Research Council of Canada

Contact information: Head, Ionizing Radiation Standards Section
Institute for National Measurement Standards
National Research Council of Canada
Ottawa, ON K1A 0R6
CANADA
Telephone: (613) 993-2715

J.2 Independent Test Specifications for Internal Dosimetry

National Calibration Reference Centre for Bioassay and In Vivo Monitoring, Health Canada

Contact information: Chief, Environmental Radiation Hazards Division
Health Canada
775 Brookfield Road
Ottawa, ON K1A 1C1
CANADA
Telephone: (613) 954-6672

J.3 Independent Test Specifications for Radon Gas and Radon Progeny

Bowser Morner

Contact information: Director
Radiological Services Division
Bowser Morner
4518 Taylorsville Road
P.O. Box 51
Dayton, OH 45401-0051
U.S.A.

[1] Last updated on June 25, 2004